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(English Edition)

Bulletin of the International Railway Congress Association

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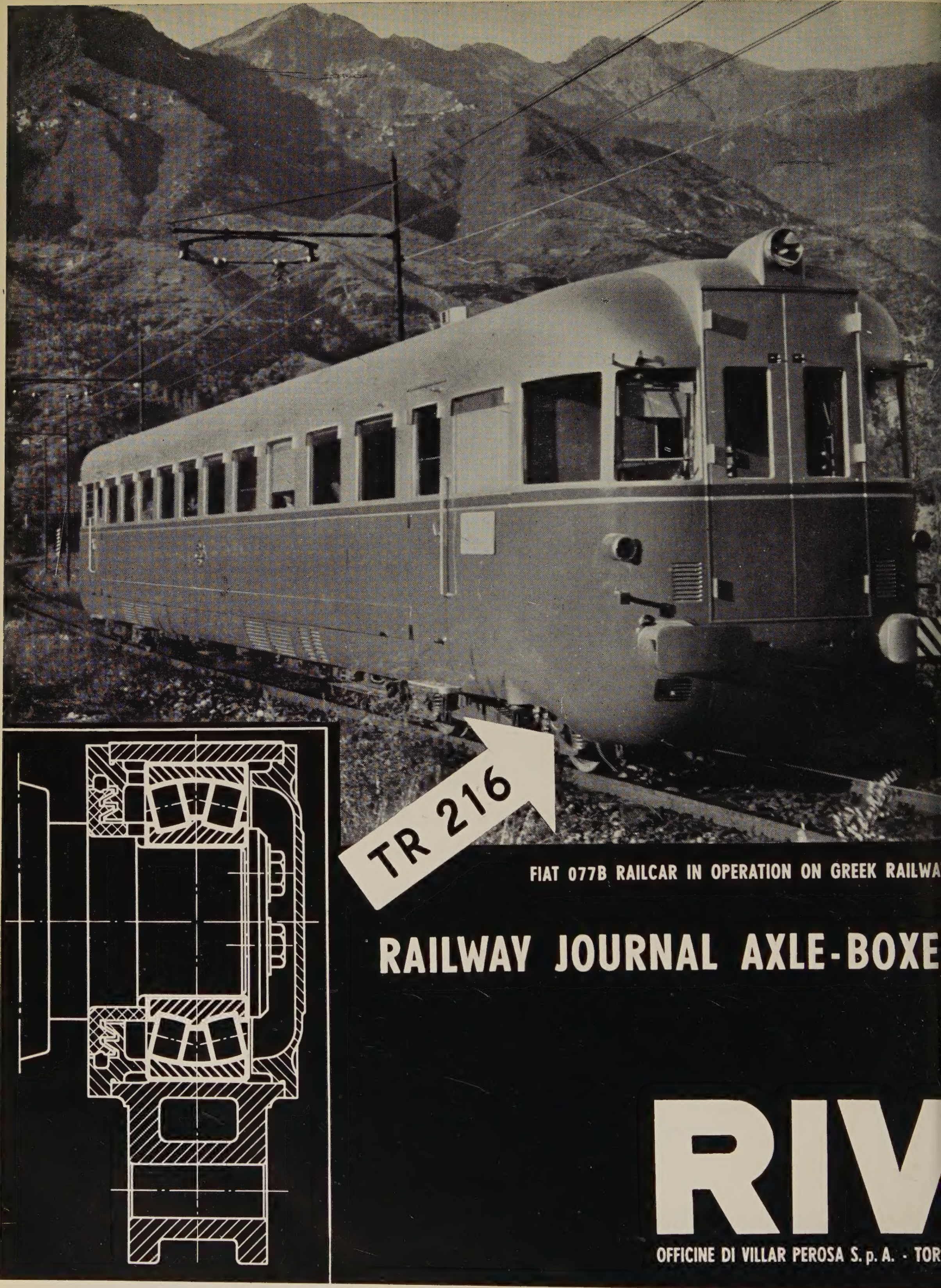

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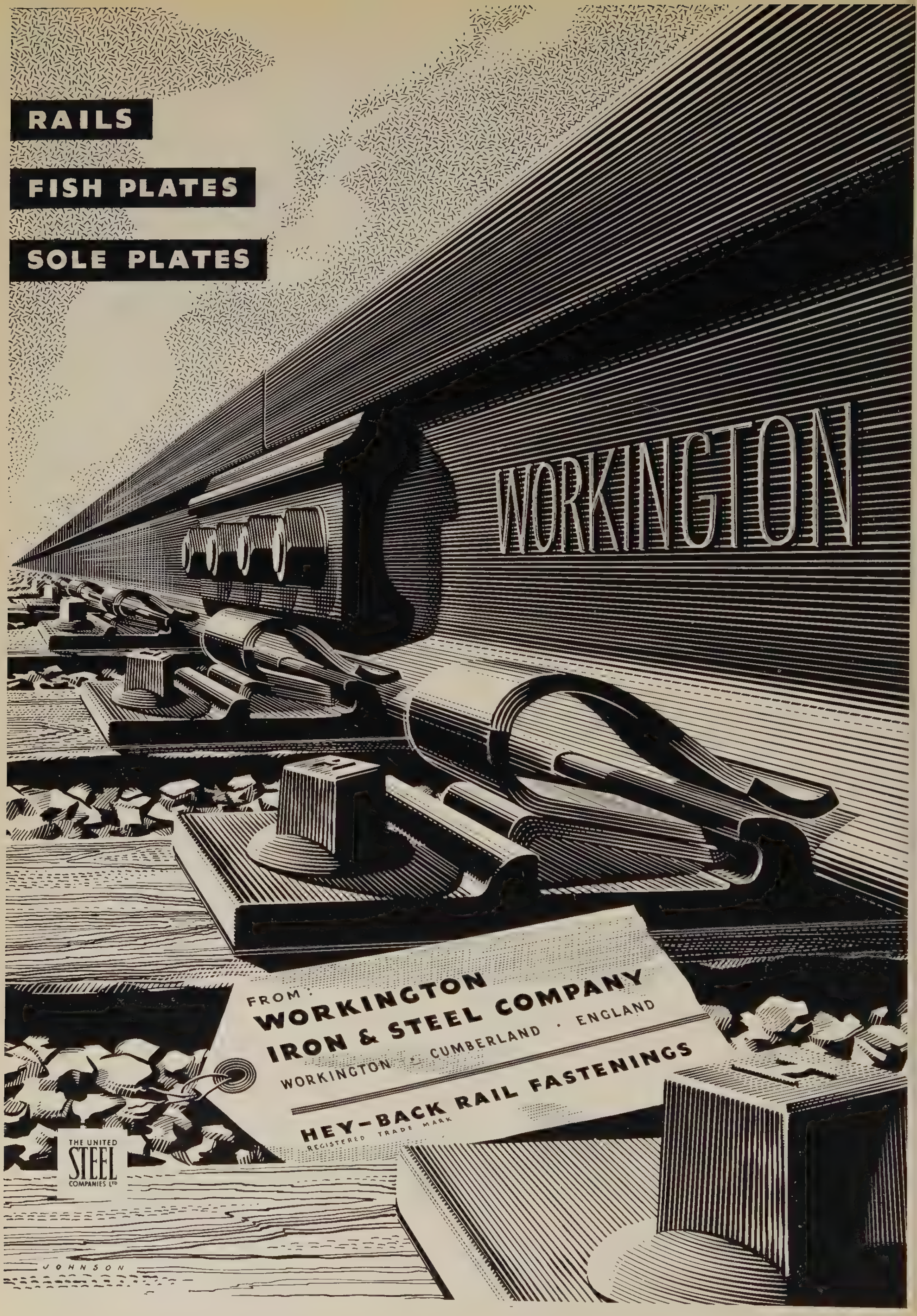

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OF THE

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(ENGLISH EDITION)

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Belgian National Railways (S.N.C.B.);
National Light Railways (Société Nationale des Chemins de fer Vicinaux) (S.N.C.V.);
Lower Congo to Katanga Railways (B.C.K.);
Upper Congo to the Great African Lakes Railways Cy;
Colonial Transport Office (O.T.R.A.C.O.) : Matadi - Leopoldville Railway.

Denmark :

State Railways (D.S.B.).

Spain :

Red Nacional de los Ferrocarriles Españoles (R.E.N.F.E.).

Finland :

State Railways.

France and French Union :

French National Railways (S.N.C.F.);
Société Générale des Chemins de fer Economiques;
Algerian Railways;
Cameroons Railways;
French West African Railways;
Franco - Ethiopian Djibouti to Addis-Ababa Railway;
Viet Nam Railways.

Hungary :

Hungarian State Railways (M.A.V.):

Italy :

State Railways (F.S.).

Luxemburg :

Luxemburg National Railways (C.F.L.).

Holland :

Netherlands Railways (N.S.).

Portugal :

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Switzerland :

Federal Railways (C.F.F.).

Syria :

Damas - Hama Railways and Extensions.

Czechoslovakia :

Ministry of Transport of the Czechoslovakian Republic.

Tunisia :

Tunisian National Railways.

Jugoslavia :

Jugoslavian Railways (J.D.Z.).

Amongst the replies received, some were very brief, whilst others merely dealt with some of the questions asked, but in most cases the replies were sufficiently detailed, and were based on a knowledge of many bridges of different types, built at different periods, so that they are a valuable contribution towards solving the problems covered by Question 1.

1. General considerations.

The replies to this part of the questionnaire are the final result of the experience acquired by the Administrations on these points, and for this reason it seems best to postpone examining them till the end of the report, i.e. after we have examined the replies to the succeeding questions, since these latter answers are the direct expression of this experience.

2. Metal bridges and viaducts.

2.11) *When checking the stability of old bridges do you express their resistance as a percentage of the typical train on which the calculations for new designs of bridges are based, or do you use the actual train loads?*

Do you take the effects of fatigue

into account in the case considered?
What fatigue and permanent stresses do you consider admissible for the iron and steel used formerly and at the present time?

This question (like the next one) has already been dealt with by the International Railway Congress Association at the Enlarged Meeting of the Permanent Commission at Lisbon, in 1949. (*Question* I *c* : Recovery and strengthening of metal bridges that have reached the theoretical limit of safety).

The second section of the preliminary report on this subject, drawn up by M. CASSÉ, (*) of the S.N.C.F., had in fact as its subject : *Regulations concerning the theoretical limit of safety.* The present report, as far as this theme is concerned, for those countries it covers, brings M. CASSÉ's 1949 report up to date.

We would point out that M. CASSÉ was able to take into account replies received from the railways of Greece, Poland, Rumania and Turkey, which in this present occasion did not reply to the questionnaire, and the present report also considers replies to questions 2.11 and 2.12 sent in by other Administrations which were not considered in M. CASSÉ's report, amongst them, some which operate important systems either in Europe (Denmark, Italy, Jugoslavia) or the Colonies (French West Africa).

The replies concerning the first part of question 2.11 as regards the loads to be taken into account when checking the stability of bridges built a long time ago show very considerable divergencies.

No Administration, it appears, habitually expresses the resistance as a percentage of the typical train adopted for the calculations of new bridges, although certain Administrations check the stability in relation to the typical train (S.N.C.B., Portuguese Railways) or in relation to a percentage of the typical train (Finnish Railways, N.S.).

Certain Administrations check it with a typical train, which differs from that used in the case of new bridges, but which corresponds on the contrary to the maximum real load; many other railways report that they check it in relation to the actual loads.

However, the difference between the various replies is perhaps more apparent than real, especially when it is remembered that the Administrations who make the calculations in relation to typical trains, when such calculations give favourable results, repeat them according to the heaviest loads, which are allowed over the bridge, and other railways who state that they make check calculations based on the real loads, might imply that these refer to a typical train which gives for all the parts of a bridge the most unfavourable load conditions corresponding to all the locomotives which may use it in practice.

If old bridges are to be checked systematically, it is obvious that the basis must be a load which will comply with all present requirements, or even in some cases those of the near future.

On the contrary, when it is question of examining the possibility of sending an exceptional load over a bridge, or even of allowing the use of a certain heavier class of locomotives, it is logical to carry out the check in relation to the load it is desired to send over the bridge.

Such calculations must be made in particular by those Administrations which, like the F.S., have electrified the greater part of their main lines and must consider the possibility of using heavier locomotives on other lines as these engines have become available.

The replies received from many Administrations show that the calculations for checking an old design of bridge cannot in any way overlook the state of conservation of the bridge itself.

For example, the S.N.C.B. states that the

(*) See « Congress Bulletin » for February 1949.

« stability of old bridges is checked after an examination of the reports made after inspecting the bridge which must list in particular all the reductions in section ».

Check calculations for old bridges must be particularly carefully made. It is necessary to take into account the stresses which may be caused by mistakes in design, which are often found in old bridges, and when such mistakes are confirmed, it is advisable for the results to be compared and completed by actual tests.

In the case of the replies to the second part of the question (Do you take the effects of fatigue into account in the case considered ?) it will be noted that most of the Administrations either take no account at all of these effects, or take them into account without making any distinction between old and new bridges. The Czechoslovakian Railways are an exception as on the basis of the results of fatigue tests on old bridges made of puddled iron, they limit for these bridges only the difference between allowable extreme stresses to 1 200 kg/cm²; as well as in practice the Swiss Railways, which lay down limits for the stresses which are a function of the maximum and minimum unit stress, but with permissible variations according to the quality of the materials used.

The Italian State Railways in calculations for checking old bridges take into account the fatigue effects only by lowering the unit stress allowable in the zones where the stresses are reversed, and keep to the same regulations in force in the case of recent bridges; they think, however, that in the case of bridges made of puddled iron, and in the case of steel bridges erected at the end of the last century, the state of preservation of a metal bridge which should be checked at the same time as the calculations are made, should also check for possible ageing of the materials by making all the necessary tests.

The F.S. in fact, as shown by their reply to the next question 2.11 attribute the greatest importance to any modifications which may have been made in the structure of the material of old bridges.

The replies given did not pay much attention to the last part of question 2.11 (What fatigue and permanent stresses do you consider admissible for the iron and steel used formerly and at the present time ?).

2.12) *Do you check old bridges using the same limits of stresses as for new bridges, or have you adopted other limits ?*

In the latter case, how do you decide these limits, for example according to the elastic limit, and if so, to what extent ?

See also question 2.23 below.

It does not seem possible to make any comparative examination of the replies received, unless this is completed by a comparison of the typical train adopted by the different Administrations and the effective loads being run on the systems of these same Administrations.

Obviously, when a new bridge is being designed, it is possible to take into account the possibility of future increases in the loads run, either by using a heaviest typical train for the actual loads, or by limiting in the calculations for the new bridges the stresses to lower values than those considered allowable in practice, or by means of one or other of these two methods. The questionnaire, however, did not ask for any such comparison between the typical train and running loads, a comparison which would have to be expressed synthetically by a number obviously greater than the unit representing the ratio between the stresses set up by a typical train and those set up by the actual loads (this figure could only be an average, as the ratio can vary according to the different loads, and on different bridges).

This factor being lacking, and it being admitted that, at least in the case of the most important European systems, the

actual loads do not differ very much, it seems we should at least stress the weight per linear metre of the locomotives of the typical train (by themselves or with the tender).

These data, as far as they are known by the reporter, have been included in *Plate 1,* in which are summed up the replies given by the most important Administrations.

It was considered useless to include in the table the replies received from the smaller Administrations, as in the case of the stresses allowed, in general, they do not depart from those adopted on the larger railways in their country.

We might point out that the replies received can be put into three groups :

a) *Administrations which make use of different limits, determined according to different principles for old bridges and new bridges.*

To this group belong : the *S.N.C.F.*, and in general all the Administrations of the French Union, who in designs for new bridges allow for a stress of 1 300 kg/cm² for the steel, whereas in checking bridges already built, they allow a stress equal to 2/3 of the elastic limit, i.e. in general 1 400 kg/cm² for iron and 1 800 kg/cm² for steel, values which exceptionally can be exceeded by 10 %.

The *Czechoslovakian Railways,* who do not state the limits adopted in calculating new bridges, in the case of old bridges allow stresses equal to 2/3 of the limit of elasticity, but express the opinion that the stresses should not exceed 1 400 kg/cm² in the case of iron, and 1 500 kg/cm² in the case of mild steel (only for the permanent weight and the load).

The *M.A.V.* (Hungary) who in calculating both old and new bridges take the limit of elasticity of the materials into account, but in different ways.

In the case of new bridges, they make use of a fictitious stress obtained by multiplying the load (typical train), after increasing it to allow for dynamic stresses, by a factor of safety greater than 1.

This fictitious stress must be smaller than a limiting stress which closely approximates the limit of elasticity (for example, in the case of mild steel, the limit tensile stress is in certain cases 1 950 kg/cm²).

In the case of old bridges, on the other hand, the effective stresses in relation to the real loads are calculated (taking into account the increase for dynamic stresses with a factor of safety of less than 1).

These effective stresses must result in an « allowable stress » which is lower than the limiting stress considered for new bridges (for example in the case of mild steel the allowable tensile stress is 1 600 kg/cm²).

The M.A.V. state the load capacity of old bridges is estimated less strictly, but they give no details about the value of the safety factor adopted in calculating new bridges, so that it is not possible to judge what this difference is.

b) *Administrations which in making calculations to check the safety of old bridges, increase the allowable stress limits by a proportional percentage.*

The *RENFE,* allows an increase of 25 % in the stress limits, which differ for iron and for steel.

c) *Administrations which adopt the same limits for the allowable stresses in the calculations for old bridges and new, but which make use of different limits of safety for the different materials.*

Included in this group are the *S.N.C.B.* (and the other Administrations in Belgium and her Colony), the *F.S.* (Italy), the Portuguese Railways, and the C.F.F.

The limits indicated by these Administrations include the increase for dynamic stresses.

PLATE 1.

Administrations	*Weight uniformly distributed of locomotive of typical train (t/m)*			*Supplementary stresses taken into account*					
	Locomotive	*Tender*	*Locomotive and tender*	*lateral force*	*braking*	*wind* kg/m²	*dynamic stresses*	*temper-ature*	*effe c fati*
S.N.C.B. (Belgium) . .	12.50	7.50	10.00		1/7th of the overloads	150	taken into account	± 30°	
D.S.B. (Denmark) .	11.00	—	11.00		1/7th of the overloads	150	taken into account	± 35°	taken accou the a when stre a rese
R.E.N.F.E. (Spain) . . .									not t in acco
Finnish State Railways . . .	11.67	—	11.67	5 tn	1/7th of the overloads	125	taken into account		
S.N.C.F. (France) . . .	11.42	10.00	10.91		1/7th of the overloads	150	taken into account	± 27°	not t in acco
M.A.V. (Hungary) . .							taken into account		
F.S. (Italy) . .	13.20	—	13.20	$L = 0.25 \cdot P \cdot \frac{50+V}{150}$ P = weight of heaviest axle V = speed km/h	1/6th of the overloads	150	taken into account	± 30°	taken accou the a when stre a reve

	Admissible stresses (tensile and compression)			Remarks
	New bridges kg/cm²	Existing bridges iron (kg/cm²)	Existing bridges steel (kg/cm²)	
00 7 7 Sc 7 HS 52 52 HS	1 200 1 400 2 100	for the stringers and bridge components : 700 for the main beams (*) : span < 10 m : 750 span < 20 m : 765 span < 40 m : 810	same limits as for new bridges.	(*) In the calculations made when checking old iron bridges, no increases are allowed for dynamic stresses.
			same limits as for new bridges when it is a question of bridges which are to remain in service for some years.	In the case of old bridges, which will not remain in service for any length of time, a certain increase in the limits is allowed.
el	1 200		same limits as for new bridges.	An increase in the limits of ~ 25 % is allowed for running new motor and rolling stock.
		in calculations when checking old bridges the same limits are allowed for the stresses as in the case of new bridges.		
42	1 300	2/3rds of the elastic limit in general. 1 400	1 800	In emergencies or for exceptional diversions, an increase of 10 % over the limit stresses is allowed. With speed reduced to 30 km/h the dynamic increase is reduced to half, and is cancelled out at 10 km/h.

For new bridges : The effect of the overload, after allowing an increase of dynamic stress, is increased for a safety ctor (> 1). By this means is calculated a fictitious decisive stress which cannot exceed the limit stress. This is close the elastic limit of the material (for example in the case of mild steel, the limit tensile stress in certain cases is 50 kg/cm²).
For old bridges : The effective stress cannot exceed the allowed stress (for example mild steel, 1 600 kg/cm²).

42 50 53	1 600 1 800	900	Mild steel : 1 400. In the case of mild steel manufactured before 1895 the admissible stress is reduced to 900.	

PLATE 1. *(Continued).*

Administrations	*Weight uniformly distributed of locomotive of typical train (t/m)*			*Supplementary stresses taken into account*					
	Locomotive	*Tender*	*Locomotive and tender*	*lateral force*	*braking*	*wind* kg/m^2	*dynamic stresses*	*temper-ature*	*eff... fati...*
C.F.L. (Luxemburg).									
N.S. (Netherlands)	14.90	6.40	11.63		1/7th of the overloads	150	taken into account	± 35°	
C.P. (Portugal)	8.90	8.00	8.51	5 tn	1/7th of the overloads	150	taken into account		
C.F.F. (Switzerland).	9.80	—	9.80		1/7th of the overloads	100	taken into account	± 30°	ta... in acc...
					not taken into account	not taken into account	taken into account	not taken into account	
Czechoslovakian Railways. . .									(**) in accou... the ca... pudd... ir... bric...

Admissible stresses (tensile and compression)			*Remarks*
New bridges kg/cm²	*Existing bridges*		
	iron (kg/cm²)	*steel (kg/cm²)*	
The C.F.L., in principle, apply the regulations of the Deutsche Bundesbahn.			
		1 400	
imilar stresses for new and existing bridges : l : 1 400; iron : 1 050; but in any case 60 % of the elastic limit 36 % of the breaking limit must not be exceeded.			
d steel 37 : 1 600	1 300	same limits as for new bridges.	
d steel 37 : 1 400	1 100		
	2/3 of the elastic limit : 1 600	1 700	(**) The difference between the maximum stress and the minimum stress must not be greater than 1 200 kg/cm².

Only the limits given by the S.N.C.B. do not taken this increase into account.

We may mention that the Italian Railways, as regards the allowable stresses, make no distinction between pre-1895 steel and iron.

d) *Administrations which in making check calculations for old bridges allow for the same stress limits as in the case of new bridges.*

To this class belong Finland, Holland, Jugoslavia.

Finland and Jugoslavia gave no details of the stresses allowed.

The D.S.B. and the C.F.L. reported that they adhere to the regulations of the German railways.

The effect of fatigue is considered, in the case of iron only, in Czechoslovakia where, as we have already seen, in the case of this material, it is laid down that the difference between the maximum and minimum stresses must not exceed 1 200 kg/cm².

Three Administrations consider the influence of fatigue in the case of both iron and steel :

a) *Only in the case of inversion of stresses :*

The F.S. (Italy) which multiply the allowable unit stresses by the factor $(1 - 0.3 \frac{A}{B})$ in which A and B are the maximum absolute values for the two stresses of contrary sign : $A \leqslant B$.

The D.S.B. which give the loads a coefficient of increase :

$1 = 0.3 \frac{A}{B}$ in the case of rivetted or bolted bridges;

$1 = 0.4 \frac{A}{B}$ in the case of welded bridges.

b) *in all other cases.*

The C.F.F. which for the allowable stresses make use of values which are a function of the ratio between the maximum and minimum stresses according to the laws resulting from the diagrams given in Plate 2.

2.21) *Have you carried out* systematic tests *on the metal components used in bridges, in order to judge how they are ageing, taking into account modifications in their strength ?*

2.22) *Have you made* systematic tests *on metal bridges themselves in order to judge how the structure is ageing, taking into account modifications in the elastic characteristics of the materials ?*

2.23) *If you have not carried out any such systematic tests, have you made any technological tests on the components of metal bridges of a certain age in order to ascertain how they are ageing in relation to the characteristics such materials may be presumed to have had when the bridge was erected ?*

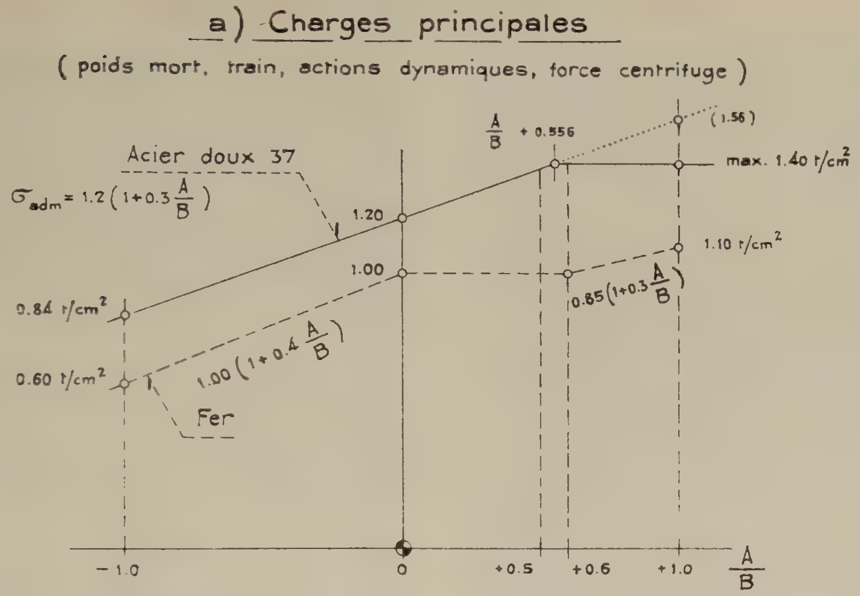
Most of the Administrations did not reply to the above three questions, or else they replied that they had never made any systematic tests or other tests on materials and bridges in order to ascertain how they were ageing.

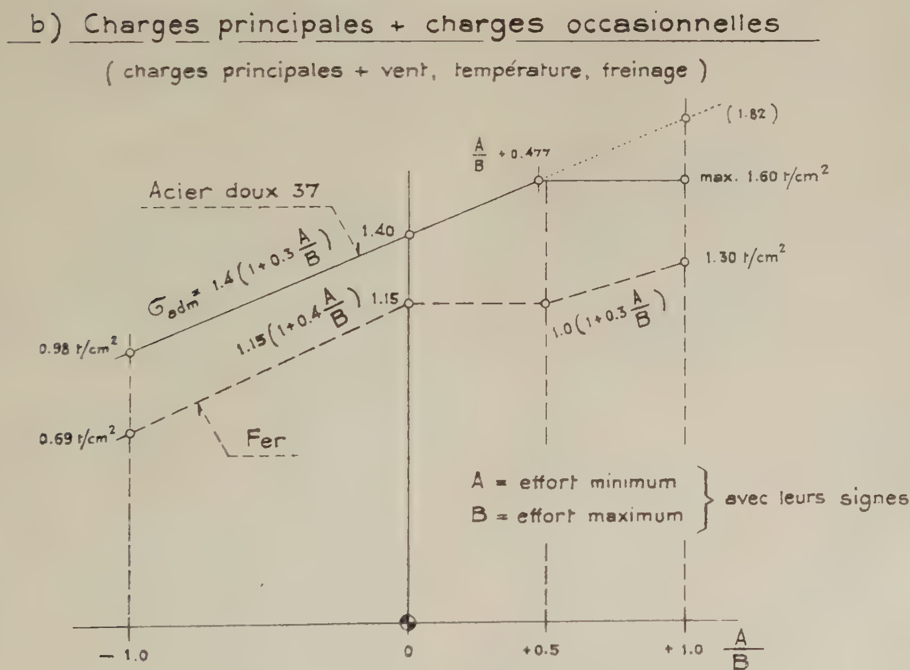
Systematic tests on the metal components of old bridges have been carried out by the Czechoslovakian Railways, who state that such tests showed satisfactory agreement with the results of tests made prior to 1885, the details of which are still kept in their archives.

The apparent limit of elasticity, the resistance, and the elongation to breaking, are practically the same.

The Hungerian Railways (M.A.V.) have

PLATE 2. — *C.F.F. : ALLOWABLE STRESSES IN T/CM² FOR METAL RAILWAY BRIDGES.*





Explanation of the French wording :

Charges principales = principal loads. — Poids mort, train, actions... = dead load, train, dynamic stresses, centrifugal force. — Acier doux 37 = 37 mild steel. — Fer = iron. — Charges principales + charges occasionnelles = principal loads + occasional loads. — Charges principales + vent, température, freinage = main loads + wind + temperature, braking. — Effort minimum = minimum stress. — Effort maximum = maximum stress. — Avec leurs signes = with their signs.

carried out an extremely interesting series of tests on the materials of nine iron bridges built between 1865 and 1896 which have been in service for 40 to 90 years.

The results of these tests are included in Table 3, which also shows the minimums laid down in the old regulations for the resistance and the elongation to breaking. As can be seen, many of the results do not conform with these regulations.

However, according to the M.A.V., as no comparison can be made between the present results and those of tests carried out when the bridges were built, which unfortunately are not known, it is not possible to form any conclusions about the ageing of the iron, as the M.A.V. have certain authentic records of the original tests on certain other iron bridges long since demolished, and these show that even at the time the bridges were built, the materials did not comply with the regulations.

The Hungarian Railways as regards the results collected in the table, think it is possible to conclude that for the real stresses, and for the quantity of repetitions reached (which in the case of the bridges considered are on the average 0.23 millions with a maximum of 0.7 millions) no manifestations of fatigue or ageing are yet apparent, event if it must be admitted that there is a certain increase in the rigidity.

These conclusions, in the opinion of the reporter, might be the subject of discussions.

In connection with the data given in Table 3, the following remarks must be made :

a) *in the case of each bridge, the results obtained with different samples show very remarkable divergencies.* In the case of bridge 11 for example, we get :

Elastic limit varying between . . .	from	18.6 kg/mm²	to	27.5 kg/mm²	with 10 test pieces;
Breaking load	from	28.5 kg/mm²	to	38.8 kg/mm²	with 10 test pieces;
Proportional elongation of	from	11 %	to	31.2 %	with 10 test pieces.

b) *For each bridge the differences between the maximum and minimum values of the elongations are either as absolute values or percentages, much higher than the differences in the elastic limits or breaking loads.*

c) *The values of the proportional elongations are often low* (7-8 %).

d) *Bending tests in most cases resulted in cracks.*

e) *As a whole, on samples from 8 of the 9 bridges (excluding bridge No. VI which should be the subject of a special study),* the following maximum and minimum values were obtained (For samples whose axis is parallel to the direction of rolling) :

Elastic limit	min. 18 kg/mm²	max. 33.2 kg/mm²;
Breaking load	min. 28.5 kg/mm²	max. 44 kg/mm²;
Proportional elongation	min. 7.2 %	max. 31.2 %;
Resilience	min. 1.2 kgm/cm²	max. 11.2 kgm/cm².

f) *Resistance to breaking in the direction perpendicular to rolling may be very reduced.*

From observation of the results given for bridge No. VII, it will be noted that fracture occurred with a load of 19.7 kg/mm² (before reaching the elastic limit).

As we have already said the results of tests on the materials of bridge No. VI are worth particular examination, on account of the large number of samples tested, and because of the special conditions on which these materials had worked.

The minimum and maximum values obtained in the tests are as follows (with samples whose axis is parallel to the direction or rolling) :

Elastic limit (on 16 samples)	min. 21.7 kg/mm²	max. 33 kg/mm²;
Breaking load (on 18 samples)	min. 32 kg/mm²	max. 40.1 kg/mm²;
Proportional elongation (on 18 samples) . . .	min. 3 %	max. 18.8 %.
Resilience (on 12 samples)	min. 0.7 kgm/cm²	max. 2.5 kgm/cm².

The values obtained for the elastic limit and for the breaking load show no special differences compared with those obtained for the 8 other bridges, whilst as regards the elongation and resilience, the results were much worse.

The test pieces were taken from the crossties of a bridge built in 1877 and demolished after 36 years in service. Ten years after demolition, these crosspieces were used to make taller full web beams, so that corresponding with the axis of the new beams the ends of the webs of the old crosspieces came together. The beams so designed remained in service for 18 years.

The Hungarian Railways, not knowing the modalities according to which the old crosspieces had been superposed, thought that in the new beams the materials might have been subjected in part to stresses of the same sign and in part to stresses of the contrary sign to that of the stresses to which they were subjected in their previous service.

The Hungarian Railways, since the minimum and maximum values of the test results were taken almost exclusively from test pieces taken from the webs, and not from the others, after having considered the remarkable differences between the maximum and minimum values, thought they could affirm that the parts subjected to stresses of the contrary sign in the two positions were more fatigued than those which during both periods had only been subjected to stresses of the same sign.

— No other Administration has carried out any systematic tests on the materials of old bridges.

Non systematic tests have been made :

a) By the Danish Railways, the R.E.N.F.E., the Portuguese Railways. These Administrations however did not give any information about the results of the tests.

b) By the S.N.C.F. (before 1936), by the « Chemins de fer Economiques » by the C.F.F. According to these Administrations, the results of the tests did not make it possible to conclude that there is any phenomenon of ageing of iron, especially on account of the lack of certainty of its supposed characteristics when first put into service.

c) The F.S. have recently made tests on samples of puddled iron from very old bridges, and have obtained results which confirm the remarkable differences found by the Hungarian Railways for the elastic limit, for the breaking load, for which the same values of 25 kg/mm² were obtained, and for the proportional elongation; but these results were even worse in the case of the bending tests which nearly all resulted in cracks in the samples.

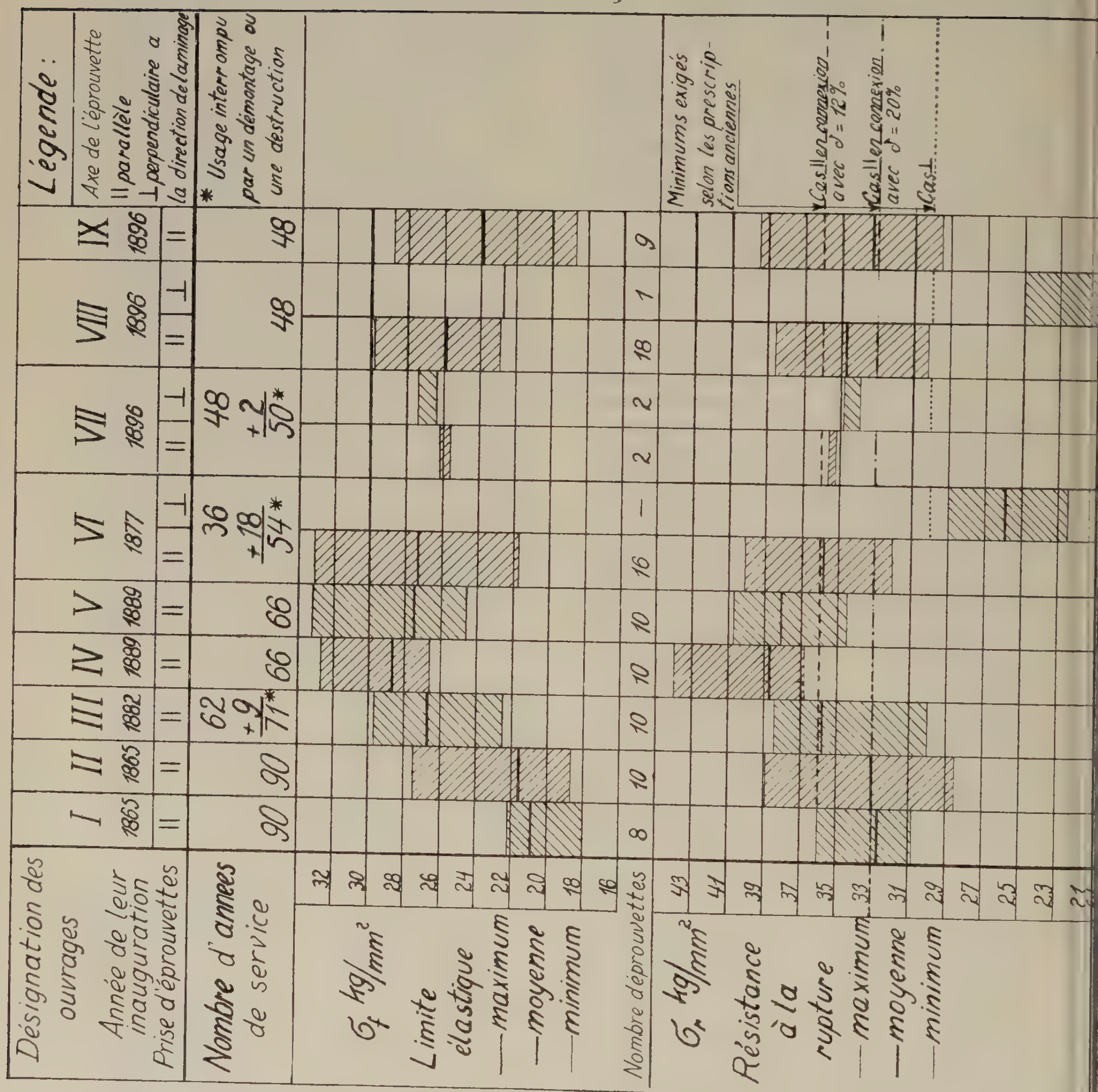
The macro- and microscopic observations brought out the very heterogeneous structure with much slag inclusions and cavities.

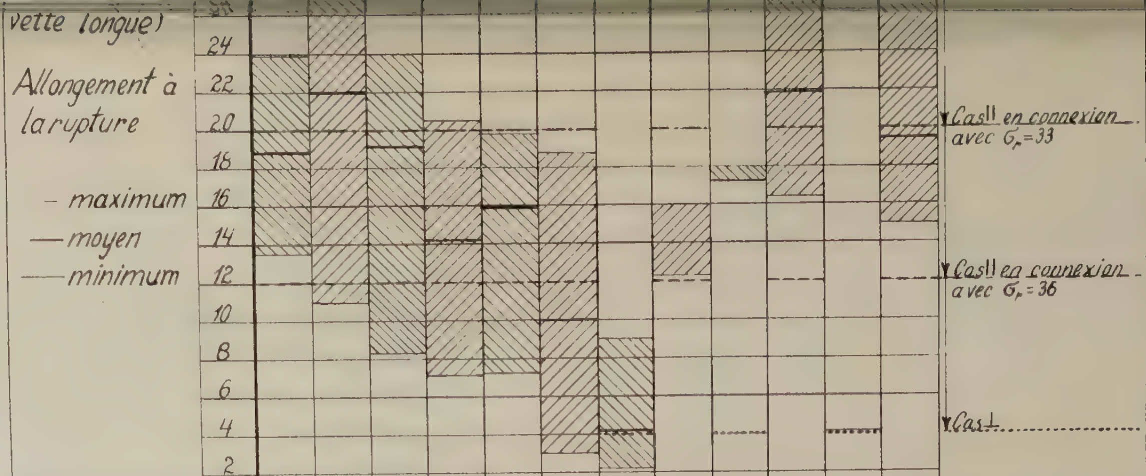
With one of these samples it should be noted that the limit of elasticity 20.8 kg/mm² is very close to the breaking load (26.6 kg/mm²).

The Experimental Institute of the F.S., which carried out these tests, concluded in its report that the iron examined was of inferior quality, and its defects had been *aggravated* by deterioration due to ageing.

— The replies to question 2.22 were for the most part negative, i.e. no Administration had carried out any systematic tests on bridges in order to estimate the ageing of the structure in relation to the modifications in the elastic characteristics of the materials.

PLATE 3. — M.A.V. : RESULTS OF TESTS OF MATERIALS OF OLD IRON BRIDGES.





Nombre d'éprouvettes	8	10	10	10	10	18	6	2	2	18	1	9	
Résilience mkg/cm² — max.	7,5	8,9	11,2	4,9	2,5	2,5	2,5	5,7	5,5	—	—	—	Dimensions de l'éprouvette: 20, 20, 40, 2, 7, 10, 10
— min.	4,9	3,6	3,5	1,2	1,2	0,7	1,5			—	—	—	
Nombre d'éprouvettes	5	6	6	5	5	12	5	1	1	—	—	—	
Résistance à la fatigue σ_r^o kgm/mm² — max.	25,0	25,0	27,0	26,0	27,0	—	—	21,5	21,0	—	—	—	Traction répétée de zéro à σ_r^o
— min.	20,0	19,0	25,0	19,0	23,0	—	—		<18,0	—	—	—	
Nombre d'éprouvettes	3	4	4	5	5	—	—	1	2	—	—	—	
Essais de pliage — satisfaisants	2	2	2	1	1	—	—	—	—	3	—	7	
Essais de pliage — fissuration	—	—	8	5	5	—	—	2	2	7	2	2	
Nombre d'éprouvettes	2	2	10	6	6	—	—	2	2	10	2	9	

Explanation of the French wording :

Désignation des ouvrages... = bridges from which samples were taken. — Année de... = year into service. — Nombre d'année... = number of years in service. — Limite élastique... = élastique limit - maximum - average - minimum. — Nombre d'éprouvettes = No. of test pieces. — Résistance à la rupture = breaking resistance. — Norme d'éprouvette longue = standard long test piece.—Allongement à la rupture = elongation to breaking. — Résistance à la fatigue = resistance to fatigue. — Essais de pliage = bending tests. — Satisfaisants = satisfactory. — Fissuration = cracked. — Légende = legend. — Parallèle = parallel. — Perpendiculaire à la... = perpendicular to the direction of rolling. — Usage interrompu par... = service interrupted by dismantling or destroying. — Minimums exigés selon... = minimum required by old regulations. — Cas en connexion avec = case in connection with.—Dimensions de l'éprouvette = dimensions of test piece. — Traction répétée... = tensile repeated from zero to Gr°.

Only the Lower Congo-Katanga Railways checks the versines every year on bridges whilst there is no load on them.

The other Administrations periodically make static and dynamic tests by checking the stresses and deflections; but such tests are simply made with the sole object of checking the actual condition of the bridge and do not concern themselves with the consequences of ageing.

The C.F.F. has carried out dynamic and fatigue tests on a railway bridge made of puddled iron dating from 1882 (crossed trellis girders of 16 m span over a single line).

In principle, these tests consisted of superimposing on a given static load, a pulsating load, which was also predetermined and checked by direct measurements.

Breaking occurred by varying the limiting stresses between 200 kg/cm² (action of dead weight) and a maximum of 1 500 to 1 600 kg/cm²: this value coincided with the endurance strength of the perforated bar obtained in the laboratory.

The C.F.F. point out that a comparison between the tests on materials carried out before and after these experiments did not show any appreciable differences in the resistance to fatigue imputable to ageing, or more precisely, to the test.

* * *

It appears in fact that an examination of the replies to questions 2.11, 2.21, 2.22, 2.23 enables us to affirm that, as regards safety rules for old bridges, there are two definitely different tendencies, the influence of which is further manifested, in the replies to succeeding questions concerning the reinforcement of metal bridges.

Some Administrations do not think that ageing can affect to any appreciable extent the strength of the metal and because of this conviction, have a tendency to allow a wide margin in the calculations for checking old designs of bridges.

Amongst these Administrations is first of all the S.N.C.F.

Other Administrations think that ageing may have an appreciable effect on the strength of the metal, and because of this conviction and owing to the fact that tests carried out on materials from old bridges have given very unfavourable results, they have been led to fix remarkably low stress limits for iron.

Amongst such Administrations are the F.S.

M. CASSÉ in his 1948 report, already quoted, affirmed: « but apart from flagrant cases of alteration of the metal due to corrosion, a reduction in the breaking limits and limits of elasticity of the metal of old bridges has never been confirmed. The minimum quality obtained at the time of construction can always be taken as a basis ».

It seems to the reporter that this very definite assertion should be corrected, or at least attenuated.

At any rate, as will be more clearly seen later on when examining the replies to question 2.4, to obvious cases of alteration of the metal by corrosion must be added those of alteration due to fatigue consequent upon defects in design or erection.

But even independently of such cases, how can we explain the widely differing results obtained by the tests carried out by the Hungarian Railways on test pieces from one and the same bridge? It seems natural to attribute them to alterations in the characteristics of the iron which have developed differently because of the different conditions under which the different components have worked.

On the other hand, even if we wish to dismiss this hypothesis and admit the presence of differences at the time of construction, this makes it necessary to take great precautions in evaluating the resistance of an old iron bridge. This resistance in fact does not depend on the average resistance of the material used in the construction of the bridge, but on the resistance of the weakest point.

2.3) *What methods do you use to examine metal bridges, including ultra-sonic tests, magnetization, X-rays, dynamic stresses (tests with pulsator machines for example) ?*

This question was interpreted in two different ways. Certain Administrations thought they should list the particular methods mentioned in the text, or other similar methods, whilst others on the contrary interpreted the question more generally. In this second category are the S.N.C.F., the F.S., and the C.F.F. whose replies agree.

The detailed examination of metal bridges is essentially visual. This examination should be particularly careful in the case of places with a sudden change of section, at assembly points, and at all places where isolated patches of rust make one suspect the presence of a crack. Defects in the tightness of rivets are revealed by hammer blows.

The examination of the general state of repair of the bridge sometimes includes checking the levels of the supports and the middle of the decking (C.F.F.).

Most Administrations proceed to check the versines and stresses by mechanical, electrical or optical extensometers, but it is rare for such tests to be used only to examine a bridge and they are generally made to obtain information of a general nature.

Only the D.S.B. states that it uses magnetization to discover any possible cracks.

Examination by means of X rays is used by the D.S.B., S.N.C.F., N.S. and C.F.F. for checking welding runs.

Ultra-sonic tests are used for the same purpose by the R.E.N.F.E., N.S. and C.F.F. exceptionally by the S.N.C.F.

The F.S., N.S., and C.F.F. have occasionally made tests with pulsator machines.

The C.F.F. report that this machine is only of interest in determining the proper frequency of a bridge and its damping out, or else for breaking tests (see 2.22).

2.4) *What are the different types of deterioration which you have found together with the approximate frequency with which these occur? Is the deterioration possibly due to:*

2.41) *fatigue of the materials;*

2.42) *defects in the materials;*

2.43) *defects in the design;*

2.44) *defects in the construction;*

2.45) *corrosion;*

2.46) *lack of maintenance;*

2.47) *other causes than those listed above ?*

The replies received are summed up in Table 4.

These replies show clearly how difficult it is to classify deterioration according to its causes.

These difficulties are due above all to the fact that except for accidental damage, it is not generally possible to attribute any given deterioration to any single cause.

Finally, there is a remarkable difference in the opinions of the different Administrations concerning certain given causes of deterioration.

2.41) *Deterioration due to fatigue.*

It is on this point that opinions differ most widely.

As we have already seen, the F.S. think that in many cases the puddled iron of old bridges has gone through a veritable process of ageing, resulting in a change of structure caused by fatigue.

Other Administrations do not admit such ageing takes place, and even amongst these latter opinions concerning the deterioration due to fatigue diverge.

PLATE 4 **Résumé of the replies received from the Administrations to question** *2.4.*

2.4) *What are the different types of deterioration which you have found together with the approximate frequency with which these occur? Is the deterioration possibly due to:*
2.41) *fatigue of the materials;*

Administrations	*2.41*	*2.42*	*2.43*
S.N.C.B. (Belgium) .	Have never noted deterioration due to fatigue of the metal.	—	Shearing of assembly rivets of the strin fastened to the bridge components or the bri components fastened to the main beams w these parts do not rest on the bottom bea plates of the beams to which they are faste Swelling of the bearing plate surfaces du rust where there is too great a gap betw rivets. Tilting of the supports due to lack of a r fastening to the bearers. Lack of rigidity of old bridges due to insuffic bedding of the cross stays in the uprights.
National Light Railways Co. (S.N.C.V.)	—	—	—
Lower Congo to Katanga Railway	—	—	—
O.T.R.A.C.O. : *Matadi Leo. Railway* . . .	—	—	—
D.S.B. (Denmark). .	It has never been clearly established that breaks were due to ageing.	No cases known of defects in materials causing damage.	In old metal bridges the necessary room repainting has not always been allowed Cracks at the ends of some of the stringers to defects in the design of assembly at the c stays (bridge over the Limfjord).
R.E.N.F.E. (Spain) .	Crystallization of the structure of the iron made it necessary to replace the bridges on the Zafra to Huelva line.	No important cases.	No cases.

defects in the materials;
defects in the design;
defects in the construction;
corrosion;
lack of maintenance;
other causes than those listed above?

2.44	2.45	2.46	2.47
—	Certain parts are too difficult of access for regular repainting : — end bridge components; — upper bearing plates of the stringers on which the sleepers of the track rest; — corrosion at the fastenings of the pressed plates of water-tight decks.	Especially during and after the war. Important deterioration in the components of metal over bridges near shunting sidings.	—
—	Corrosion is the most frequent cause of deterioration.	—	—
—	—	—	The only deterioration noted has been due to shocks received from too wide loads.
—	Yes.	Yes.	—
...ctically, no damage has ...n noted which could be ...ribed to defects in cons...ction. Naturally, the ...lity of the construction ...ies. ...wever, it has been noted ...t if the angles are cut off ... sharply cracks may ...cur.	The incidence of corrosion is closely bound up with the climate. The D.S.B. make a distinction between bridges in sea water, industrial and soft water areas. Corrosion occurs above all between rivetted surfaces. Formerly insufficient care was taken to protect such surfaces and the distances between rivets were too small.	Formerly the maintenance of metal bridges was the job of the ordinary permanent way maintenance gangs and this often led to poor results.	
...fects in construction are ...ver very extensive.	On the Betanzos to El Ferrol line, serious corrosion made it necessary to replace some 44 year old sections.	Damage due to lack of maintenance has never been very great and was easily repairable.	No other causes.

PLATE 4. *(Continued.)*

Administrations	*2.41*	*2.42*	*2.43*
Finnish State Railways	A reduction was noticed in the elasticity of the material. Breaking of one of the two iron bars of a flat iron diagonal : 2 × (90 × 15) (50 year old bridge).	—	—
S.N.C.F. (France) .	Fatigue of materials does not appear to play any definite part in the deterioration noted. Cracks or breaks only occur in badly proportioned or arranged components and can be attributed to the excessive stresses due to the poor designs. It is not impossible that certain effects of fatigue are added to these stresses, but this is only a hypothesis.	Rarely : double plates for example which are pushed apart by the spread of rust.	— Inaccessible cavities and corners that can be cleaned and repainted; absence or in ficiency of flanges on the arrangements draining off the water. — Rivets too far apart. — Insufficient windbracing. — Faults in design affecting in particular t fastening of the stringers to the brigde co ponents : insufficient overlap of the string on the bridge components; rivets pul out, poor continuity of the stringers.
Société Générale des Chemins de fer économiques (France) . .	—	—	Weakness in the assembly of the stringers v the cross stays.
Algerian Railways . .	Doubtful and rare.	Rarely (flaws in certain old iron bridges).	Rarely.
Cameroons Railways .	—	—	—
French West African (A.O.F.) Railways .	—	—	—

2.44	2.45	2.46	2.47
—	—	—	—
... he oldest bridges, there ... ometimes cases of rivets ... onger filling up their ... s, or insufficiently tight, ... oth.	The most serious deteriorations are due to corrosion.	Most often.	Derailments and over wide loads.
—	Reduction in the section of certain parts particularly in the case of bridges exposed to salt laden air or smoke.	—	—
... ely.	This is the most frequent cause.	No.	Accidents (derailments, etc).
—	Yes, the climate of the Cameroons is hot and humid.	Yes, particularly on account of ageing of the paintwork.	—
—	Above all.	—	—

Administrations	*2.41*	*2.42*	*2.43*
Djibouti to Addis Ababa Railway	No.	No.	Fastenings of the stringers on the Nello Viad
Viet-Nam Railways .	30 %	3.5 %	0.5 %
M.A.V. (Hungary) .	No deterioration due to ageing of the material has been noted.	No.	Fairly frequent in the case of old bridges. Mainly : — the junction of the stringer and the c beam is weak; — in the chord members of treillis gi bridges with centres no corner plates h been used and the fastenings are diss metrical.
F.S. (Italy)	The F.S. have noticed that on most old bridges the material (puddled iron) has undergone a profound transformation and shows a crystalline structure. In general, it is not possible to carry out any work on such iron, and the repairing of the cracks which sometimes occur is very difficult, in fact often impossible.	Except in the case of old bridges made of puddled iron and materials supplied during the war, defects in materials are rare.	In old bridges, faults in design are very frequ insufficient fastening of the stringers to cross stays, asymmetrical trellis bars, exces distance between rivets, lack of transve rigidity, parts difficult to get at, bars form caissons, etc.
C.F.L. (Luxemburg) .	None.	Cracks in the web of the beams and in the thickness of the corner plate sheets (fairly rare)	— Especially on old bridges. — Too close a construction making maintenance of the paintwork difficul impossible; too great horizontal surface which water can collect. Rivetting in inac sible places. Bolts instead of rivets. plates between the main beams and supports. Too many rollers in the sup equipment, rivets too widely spaced.
N.S. (Netherlands) .	None in the case of fixed bridges, several in the case of movable bridges	In about 12 cases.	Five.

2.44	2.45	2.46	2.47
	Yes, in humid districts and near the Indian Ocean.	No.	Metal bridges laying at the entry of curves, which gives rise to abnormal transversal stresses and in the case of small bridges leads to deformations in the end cross stays and tends to upset the beams.
	60 %	60 %	—
...al, no.	Recently considerable corrosion has been noticed on the metal bridges of the system, especially on overhead bridges due to the effects of smoke from the locomotives. There is no doubt that the poorer grade paint also has an effect, so that more frequent repainting (every 3-4 years) is not sufficient to balance the deterioration.		Heavier vehicles than those allowed or running at higher speed than that allowed (one or two cases during the last 25 years). Over wide loads (rare). Shifting of the load (fairly rare).
...ciently carefully ...off cut edges, badly ...s, rivet holes not ... reamed out.	The effects of corrosion are very serious, especially in places difficult to get at.	Lack of maintenance aggravates the effects of corrosion.	Sometimes derailments and excessively wide loads have caused serious deterioration.
...oles not reamed out. ... rivetting. ...s of steel in contact ...ted with white lead. ... badly adjusted in ...port equipment. ... surfaces of the sup- ...lates not parallel.	Steel weakened by corrosion due to lack of maintenance of the paintwork; or else the paint does not stand up to permanent humidity.	During the war the work was neglected so that it has become necessary to reinforce or replace various components of the metal bridge.	In the case of metal overbridges and crossovers much exposed to smoke from the locomotives, some paint does not stand up to the sulphuric acid which is thereby added to the destructive elements. Complete elements have had to be reinforced or replaced, the wear being as much as 30 to 50 %.
...wn.	Very few.	No.	Over-running (navigation) collisions, rivets getting loose.

PLATE 4. *(Continued.)*

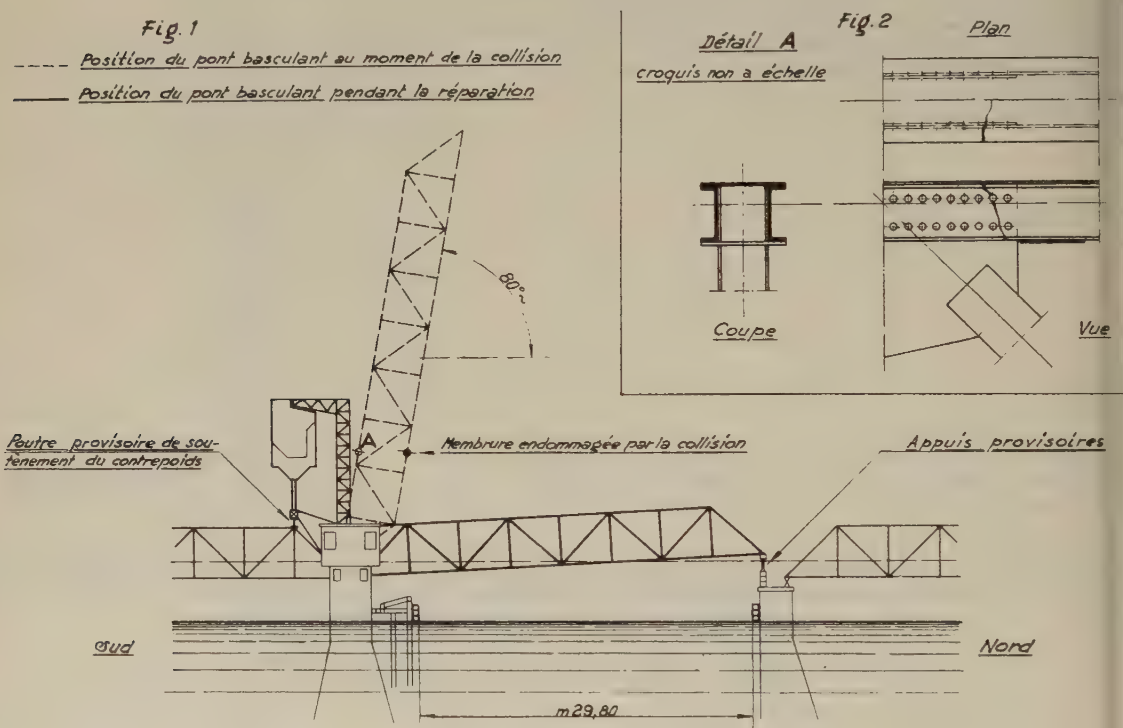
Administrations	*2.41*	*2.42*	*2.43*
Portuguese Railways .	Ageing of the material.	—	Yes above all on old bridges.
C.F.F. (Switzerland) .	Oblique cracks in the ends of stringers, in the web, in the case of stringers ending in line with the cross stays. Cracks in too thin windbracing bars subjected to vibration (at the fastenings). Dislocation of the rivets fastening the stringers to the cross stays. Cracks in the angles of the chord members of composite beams in line with the supports. Cracks starting from insufficiently rounded off edges. Rail joints facilitate the formation of cracks and loosening of the fastenings of the stringers.	Nothing particular to report except the breaking off of the heads of some rivets and cracks in the stringers of one bridge; cause : the iron breaking.	See under 2.41. In addition : Deterioratio the fastenings when the rails are faste directly to the metal structure. Rollers of the support devices flattened, deter ation of various supports (lack of cent plates, insufficient anchorage against nega stresses). Difficulty of maintaining inaccess parts (corrosion). Badly placed rivets har tighten up.
Damas Hama Railway (Syria)	—	—	—
Czechoslovakian Ministry of Transport . .	Breaks have been noted due to fatigue : — in the main beam of a temporary welded bridge; — in a welded stringer.	Longitudinal cracking of puddled iron components; stratification of mild steel components due to re-rolling cold.	Insufficient transversal rigidity due to too s a gap between the main beams and insuffic windbracing. — Excentricity of the diagonals which often made of flats; — Dissymmetrical assemblies; — Excessive gaps between rivets; — Trellis bars rivetted directly to the we the chord members without corner pla — Bars not meeting properly at the joi — Faulty arrangement of the windbrac — Insufficient fastening of the stringers to bridge components.
Tunisian Railways . .	Up to the present no serious deterioration has been noticed in metal bridges, the oldest of wh		
Jugoslavian Railways .	The Jugoslavian Railways have no statistical data available concerning the different kinds		

2.44	2.45	2.46	2.47
bove all on old bridges	—	—	—
fficiently carefully ded off (not reamed or d) edges have led to ks. Dislocation of fastgs where the rivets have badly set. king of badly set bearlates. Shearing of angle s of chord members by upright on the support n the bearing plate is too l	The Zores rolled bars carrying the macadam of road bridges can be eaten right through in thirty to fifty years. Serious attacking of the webs of full web beams of road bridges in contact with the macadam. More marked attack of bridges just outside stations by sewage. More rust in inaccessible parts.	The only cases to be reported are given in 2.45 (corrosion); the attack was not visible.	Some cracks in the welded reinforcements of iron bridges.
k of counter deflection, ly set support equipt.	General corrosion due to the humide marine climate.	—	—
—	Effects in general less marked with iron than with steel. Corrosion frequently occurs : — in the assembly of the metal covers with the framework of the bridge; — in the protective cross stays; — in the assembly of the bridge components with the main beams; — in triangular main beams in general with composite section bars when the interstices are too small so that the paintwork cannot be renewed.	Lack of maintenance of bridges especially in industrial regions and near stations is the cause of deterioration due to corrosion (see 2.45).	—
e built about 1880.			
eriorations.			

Certain Administrations, chief amongst them the S.N.C.F., consider that even the cracks and breaks which occur in certain incorrectly dimensioned or assembled components may be due to excessive stresses which are the consequence of these defects in design, and they think that the possibility that, in addition, to these excessive stresses there is a real effect of fatigue is merely a hypothesis, not impossible, but not proved by experience. Other Administrations, amongst them the C.F.F., attribute to real fatigue stresses certain cracks which have been caused above all by poor constructional arrangements, or other defects in design.

2.42) *Damage due to defects in the materials are extremely rare.*

An interesting example of damage which appears to be due to defective materials is that reported by the D.S.B. in their reply to question 2.81.



Figs 1 and 2. — *D.S.B.* : Limfjord railway bridge.

Explanation of the French wording :

Position du pont basculant au moment de la collision = position of bascule bridge at the time of the collision. — Position du pont basculant pendant la réparation = position of bascule bridge whilst repairs were being carried out. — Poutre provisoire de... = temporary beam supporting the counterweight. — Membrure endommagée par la collision = chord member damaged by the collision. — Appuis provisoires = temporary supports. — Sud = South. — Nord = North. — Fig. 2 : Croquis non à échelle = drawing not to scale. — Plan = plan. — Vue = view. — Coupe = section.

The railway bridge over the Limfjord has a swing span of 29.80 m (fig. 1).

While the bridge was raised, a boat collided with one of the lower chord member which was seriously deformed. At the

corresponding part of the top chord member, which was not struck, one of the irons was found to be completely broken and a bearing plate was half broken (fig. 2). The D.S.B. state that mechanical tests on the materials proved that they corresponded to the specifications. But after a chemical analysis was made, it was found that the steel contained a high proportion of sulphur and phosphorus which might have been the cause of its fragility.

2.43) *Damage due to defects in the design are very frequent in the case of old bridges.*

In a great many cases these defects are the primary cause of the fatigue of the materials and the resulting cracks. For example, this happens when the bolts fastening the crosspieces to the cross stays are too far apart, which get loosened when there is a pull on the heads. In other cases, faults in design lead to the construction of bridges that are inaccessible, and consequently, it is impossible to paint them thoroughly, thus encouraging rust.

2.44) *Defects in construction are rare in new bridges.*

In old bridges there are frequently cases of bad rivetting (holes not reamed out, rivets which do not completely fill the holes or are not tight enough). Surfaces where sections were cut which have not been filed or ground down may be the cause of cracks.

2.45) *Corrosion in the greatest enemy of metal bridges,*

but it occurs wherever faulty constructional arrangements encourage water to collect and make it difficult to paint the bridge, or when maintenance is not adequate for the locality in which the bridge is situated.

2.46) *Lack of maintenance is due in certain cases to defects in organisation,*

but more often it is due to exceptional causes, such as the war which led to serious deterioration as most Administrations have reported. Amongst the European Administrations, only the N.S. do not consider lack of maintenance to be amongst the causes of deterioration, and the C.F.F. point out that the only damage due to defects in maintenance are those which occur at places difficult of access.

The R.E.N.F.E., state that such damage is always insignificant, and easily made good. The S.N.C.B., S.N.C.F., Cameroons Railways, F.S., and the Czechoslovakian Railways, on the other hand, attribute the greatest importance to damage due to lack of maintenance.

2.47) *Amongst other causes of deterioration, mention must be made of the smoke from locomotives in the case of overbridges.*

Damage due to accidents, derailments, excessively wide loads, collision with moving parts, etc., are rare.

2.5) *What are the structural components principally affected by the deterioration due to the causes listed under 2.4) above :*

- 2.51) *main beams with full web, composite or laminated;*
- 2.52) *main trellis girders, straight or arched;*
- 2.53) *wind bracing and cross beams;*
- 2.54) *longitudinals and crosspieces, as well as their assemblies;*
- 2.55) *sheets and plates used for the decking;*
- 2.56) *arrangements for collecting and draining off water ?*

2.51) The main defects found in main girders with full web are the following :

a) swelling due to the formation of thick layers of rust, between the bearing plates of the booms (S.N.C.B., « Chemins de

fer Economiques », Djibouti-Addis Ababa Railways, F.S., Czechoslovakian Ministry of Transport);

b) cracks in the angles of the booms of the main girders in line with the supports (C.F.F., C.F.L., F.S.);

c) corrosion of the web in contact with the macadam in the case of road bridges (F.S., C.F.F.);

d) serious corrosion in the web where it is lined up which the decking, particularly in the case of water tight decks (S.N.C.B., S.N.C.F., Algerian Railways, Czechoslovakian Ministry of Transport);

e) corrosion inside the caisson formed by twin beams (S.N.C.F.);

f) wear of the lower webs in line with the cross stays (C.F.L.);

g) corrosion of the lower flanges and web of the girders above steam operated lines (S.N.C.B., S.N.C.F., C.F.L.);

h) corrosion of the upper flanges which carry the track directly in line with the support of the sleepers (C.F.F.).

2.52) The deterioration reported under points *a*), *b*), *f*), *g*) and *h*) of the previous paragraph are found both in the case of main girders with full web and in the case of trellis girders. In the case of trellis girders, particularly those with multiple trellis, mention is made, but in a different way, of a number of drawbacks due to the fact that the bars do not correspond at the joints and to lack of symmetry in the bars themselves.

As a result of the excentricity of the assembly of the bars at the booms, deformation has been found in the diagonals (Algerian Railways, F.S., Czechoslovakian Ministry of Transport) and in the webs of the booms (F.S.).

In such assemblies, the rivets sometimes have been found out of place (C.F.F.). The incorrect assemblies lead to continuous vibrations in the bars, facilitate the imperfect adhesion of the surfaces in contact, and consequently the formation of rust, both in the assembly of the diagonals with the booms and where diagonals cross (R.E.N.F.E., Czechoslovakian Ministry of Transport).

Mention is also made of:

— Maintenance difficulties, and consequently corrosion at the fastenings of the cross stays (C.F.L.);

— Serious corrosion in the lower booms, when these are assembled in such a way as to facilitate water tightness (R.E.N.F.E., Algerian Railways, F.S.), as in the case of main girders with full webs, or with lower bearing plates which are not divided up, or when the booms consist (as sometimes happens on certain old bridges some of which are still in use on the F.S.) of flanges and two angles whose vertical faces are not in contact, to which the flat bars of the trellis are rivetted;

— Breaking of flat iron diagonals. The Finnish Railways report such a case. On one bridge on the F.S. (which has long since been replaced), which consisted of four main trellis girders, four adjacent diagonals working under traction were found to be broken right through in line with the point where they crossed bars in compression;

— Cases of deformation and breakages, especially in the uprights and diagonals due to collisions or as a result of derailments, or to too wide loads (Lower Congo to Katanga Railways, S.N.C.F., F.S.);

— Some cracks in the welded reinforcements of iron bridges (C.F.F.).

2.53) In old designs of bridges the wind bracing is often insufficient (Czechoslovakian Ministry of Transport). The wind bracing bars are too long and bend, the connections with the booms are defective (Algerian Railways, F.S.). When the wind bracing bars are too long and thin and subject to vibration, cracks have some-

times been found in the fastenings (C.F.F.).

The wind bracing is one of the components mainly affected by corrosion (S.N.C.V.), which is the most serious in line with the points of fastening (S.N.C.B., Algerian Railways, F.S.) particularly at the fastenings with the cross stays (C.F.L., Czechoslovakian Ministry of Transport). According to the R.E.N.F.E., the wind bracing is even more exposed to corrosion in the case of an underbridge.

2.54) The crosspieces and stays as well as their assemblies are the structural components in which deterioration is most frequently found due to all sorts of causes (O.T.R.A.C.O, D.S.B., R.E.N.F.E., S.N.C.F., « Chemins de fer Economiques », Cameroons Railways, F.S., Portuguese Railways).

a) Dislocation of the rivets fastening the crosspieces to the stays (S.N.C.B., Algerian Railways, Djibouti-Addis-Ababa Railways, M.A.V., F.S., N.S., C.F.F., Czechoslovakian Ministry of Transport).
Formerly, the arrangements used for these fastenings, were often defective and the spikes generally tended to pull off their heads.

b) This defect was also found in the case of the fastenings of the cross pieces to the mains girders.

c) Insufficient fixing of the bridge pieces in the uprights of the main girders may sometimes lead to a lack of rigidity in old bridges (S.N.C.B.).

d) Cracks in the ends of cross pieces, in the web, in the case of crosspieces parted in line with the stays (D.S.B., C.F.F.). A case of this kind can be seen in figure 3 (Bridge over the Limfjord, D.S.B.).

e) Cracks in the vertical assembly angles of the cross ties on the stays (Light Railways).

f) In certain cases the metal decking is fixed to the upper web of the cross ties. The bolt holes get enlarged and corrosion and cracks occur (see fig. 4: Czechoslovakian Railways).

g) Often the surface of the end parts of the bridge that come up against the protective wall is difficult to get at, which makes it difficult to keep it painted (S.N.C.B., Viet-Nam Railways).

h) The bearing plates or upper angles of the cross ties are readily attacked by rust, particularly where the wooden details of the track rest on them (S.N.C.B., S.N.C.F., C.F.L., Viet-Nam Railways).

i) Derailments can cause serious damage to the upper webs of the bridge components (S.N.C.F., F.S.).

The cross ties, the stays and their assemblies, are subject to more serious deterioration on account of corrosion in bridges over lines operated by steam traction.

2.55) The sheets and plates of the decking are amongst the components most affected by corrosion (S. N. C. V., O.T.R.A.C.O., D.S.B., « Chemins de fer Economiques », Algerian Railways, Djibouti to Addis Ababa, C.F.L., N.S.), and must be very carefully maintained (S.N.C.F., see No. 2.77).

Corrosion is particularly serious at the fastenings to the supporting elements (see No. 2.51 and 2.54 also) and around the strainers.

When the deck consists of reinforced concrete slabs, these sometimes crack as a result of the vibrations, or because they have been badly made, or carelessly handled (C.F.L.).

The sheets and plates of the decking can suffer serious damage if derailments occur (S.N.C.F.). Deterioration of the sheets of the deck are the subject of the replies to the following question.

2.56) This question was only answered by:

— the S.N.C.B. according to whom the channels in line with the fastenings are subject to deterioration;

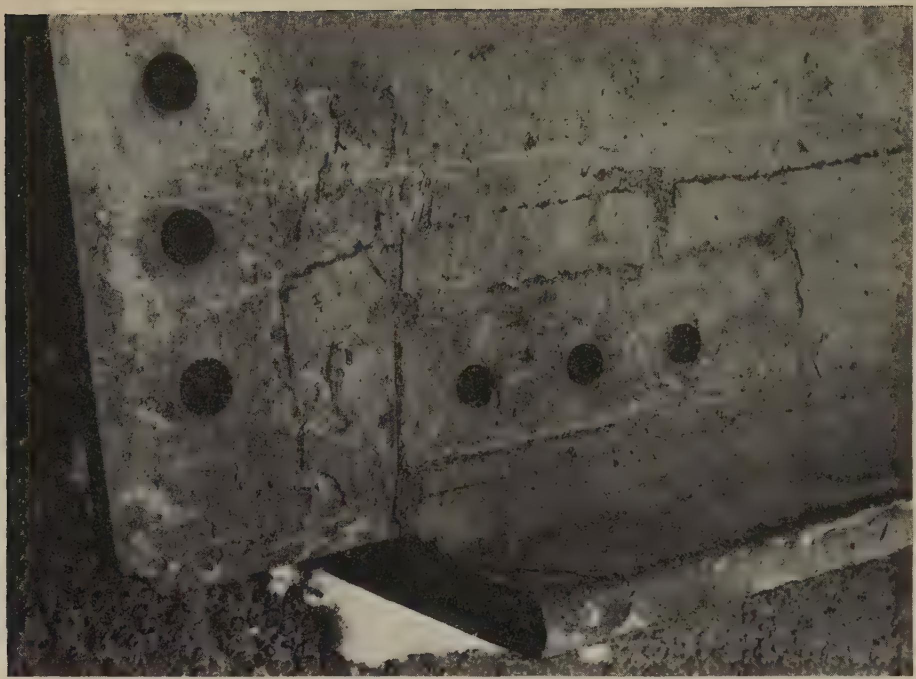


Fig. 3. — *D.S.B.* : Bridge over the Limfjord; crack in the web of a stringer in line with a cross stay.

Fig. 4. — *Czechoslovakian Rys* : Effects of corrosion.

— the R.E.N.F.E., who in order to drain off the water collected in the sheets and plates, have made slopes and holes in the lower parts without obtaining satisfactory results.

The Algerian Railways also state that to make sure the water drains away, the sheets used for the floors are perforated with holes at fairly close intervals. The Algerian Railways add that additional holes are bored in the hollows when the sheets become deformed, and that in the case of new floors, the metal is pressed in line with each hole so as to make a small hollow and thus prevent the water spreading out under the sheets. If this is not done, an area of rust rapidly forms around each holes, about 0.05 m in diameter.

The Viet-Nam Railways write : « Such arrangements rapidly deteriorate. »

The C.F.F. *state that such arrangements are subject to corrosion and vibration*

Even though the supporting components are not specially mentioned amongst the structural components listed in question 2.5, the replies mentioned deterioration and damage in this case also, as well as in the masonry carrying them.

The stone supporting blocks used in old bridges and the reinforced concrete binders which have been insufficiently compacted, crumble under the heavy pressure exerted by the bearing plates, hence the sinking of the support and the difference in level between the different supports of a bridge, and the torsion in the deck as a whole (S.N.C.B.).

Tipping of the supports : The S.N.C.B. writes that this drawback must be avoided by fixing the plates of the supports by means of fixing bolts sealed into the abutment. The C.F.F. also consider it necessary to provide adequate fixing against negative stresses.

The F.S. on the other hand retain these dangerous fixing bolts. Tipping should be avoided by a careful installation of the supports. Metal bridges of very small span (< 6 m) should not be built, as in the case of such bridges on account of their limited weight, it is difficult to prevent this phenomenon, and even in the case of continuous spans, there must not be any possible chance of negative support stresses.

— Rollers of bearings of reduced height (C.F.F.).

— Breaking of badly laid bearing plates (C.F.F.).

— Old types of support bearing poorly ventilated, and difficult of access (S.N.C.F.).

— Too many rollers in the bearings (C.F.L.).

— Badly adjusted rollers in the bearings C.F.L.).

2.6) *What steps are taken when there is serious deterioration affecting the strength of the bridge, whilst awaiting definitive overhaul? Examples : reducing the speed of the trains, reduction in the loads allowed, temporary repairs, introduction of temporary components or supports.*

The question was worded in general terms and the replies received were also generical. Thus :

— the Lower Congo to Katanga Railways replied that they have no fixed rules;

— the D.S.B., the Viet-Nam Railways, the M.A.V., the F.S., the C.F.F. and the Jugoslavian Railways have tried all these different measures. The choice depends on the nature and seriousness of the deterioration, as well as the component affected;

— the D.S.B. adds that any measures involving inconvenience for the operating is avoided as far as possible. The Viet-Nam Railways state that it is very rare to reduce the allowable load;

— the F.S. also state that it is very rarely necessary to reduce the allowable loads

on a line, but report the case of a bridge with a span of 43 m built a very long time ago, over which, on account of the ageing of the iron, it has been necessary to forbid the running of any locomotives, even of the lightest types, so that until a new bridge can be built, the services are exclusively by light railcars;

— the S.N.C.F. gave the most detailed reply, and we quote this in full below :

« In normal times (i.e. apart from damage due to the war) serious deterioration is exceptional for both railway and road bridges. When it occurs, it is generally propped up (for example by supporting the deck by a scaffolding of sleepers, which can quickly and easily be procured, or by wooden trestles) and the necessary provisional repairs are made (plates fastened to cracked parts...).

» In the case of railway bridges, first of all speed restrictions are imposed, the trains having to slow down to 30 km/h or 10 km/h. It is only when such speed restrictions do not appear to relieve the bridge sufficiently that a decision is made to forbid certain categories of heavy locomotives until the final repairs are completed.

» In the case of road bridges, the Highway and Bridges Authority are asked either to impose speed restrictions on the road vehicles, or forbid the passage of those exceeding a certain tonnage, or else to divert the road traffic over another route. »

Plate 5 sums up the replies received to question 2.6.

2.711) *What methods are used to protect metal bridges against corrosion? Painting, metallization, chemical processes, composition of the metal (for example addition or copper).*

Even though, in special cases, as we shall see later on, certain Administrations use metallization, or embedding in concrete, or even in certain cases, have made experiments using steel with copper or chrome added, the method most generally used to protect metal bridges against corrosion is still in most cases painting.

2.712) *When designing metal bridges, is it the practice to increase the calculated sections in steel in order to allow for future losses through corrosion? If so, for what components, and to what extent?*

From the replies received, it does not appear that some Administrations increased the calculated section of the steel members in order to allow for future losses through corrosion.

Some Administrations however report that in the case of bridges subjected to stresses, they lay down a minimum thickness for the metal members, independently of the results of the calculations. This minimum thickness is 6 mm for example on the Belgian National Light railways, 8 mm on the S.N.C.B., Danish Railways and S.N.C.F.; 10 mm on the F.S.; and 12 mm on the R.E.N.F.E.

From the replies received, it appears either implicitly or explicitly that there is a conviction that losses in section due to corrosion should not be taken into account, but that corrosion (the consequences of which cannot be estimated a priori) must be avoided, especially in the main components, either by careful study of their constructional arrangement, or by very careful maintenance.

In Table 6 the replies received from the different Administrations regarding the question of painting have been summarised (2.721 to 2.725 and 2.728).

2.721) *Please state what anti-rust paints you use for old and new bridges, and indicate the number of coats used, as well as the method of application.*

PLATE 5. — **Measures applied when serious deterioration affects the strength of a bridge** *(2.6)*.

Administration	*Reduction of the train speeds*	*Reduction of the loads allowed*	*Temporary repairs*	*Addition of temporary components*	*Addition of temporary supports*
S.N.C.B. (Belgium)	yes	yes (after checking the weak parts by means of calculations).	—	strengthening the track by laying additional rails on the lines.	—
S.N.C.V. (Belgium)	—	—	—	yes	yes
Lower-Congo to Katanga Rlys.	no fixed rules				
O.T.R.A.C.O. Matadi-Leo Ry.	yes	—	—	—	—
D.S.B. (Denmark)	yes	yes	yes	yes	yes
R.E.N.F.E. (Spain)	yes	—	yes	—	yes
C.F. Finland	yes	yes	(in certain cases)	—	(in certain cases)
S.N.C.F. (France)	yes	yes	yes	yes	yes
Société générale des Chemins de fer économiques (France)	yes	—	—	yes	yes
Algerian Railways	yes	—	yes	—	—
Cameroons Railways	yes	—	—	—	—
French West African Rlys	—	—	yes	—	—
Djibouti to Addis Ababa Railway	yes	—	—	—	yes
Viet-Nam Railways	yes	yes	yes	yes	yes
M.A.V. (Hungary)	yes	yes	yes	yes	yes
F.S. (Italy)	yes	yes	yes	yes	yes
C.F.L. (Luxemburg)	yes	—	—	—	yes
N.S. (Netherlands)	yes	yes	yes	—	—
C.P. (Portugal)	yes	yes	—	—	—
C.F.F. (Switzerland)	yes	yes	yes	yes	yes
Czechoslovakian Ministry of Transport	yes	—	—	yes	yes
Tunisian Railways	Have not noticed any serious deterioration up to the present.				
Yugoslav Railways	yes	yes	yes	yes	yes

PLATE 6. — **Résumé of the replies received from**

Administrations	*2.721. Anti-rust paints used :* *(a) for new bridges*	*(b) for old bridges*	*2.723. Special paints used in special circumstances or for trial purpos*
S.N.C.B. (Belgium) .	*in the shops :* under cover after pickling (maximum time : 2 to 3 h) 1 coat of lead paint applied by brush *on site after assembly :* a second coat of lead paint 3 coats of white lead paint	*in general :* pickled parts are touched up with 2 coats of lead paint 1 or 2 coats of white lead paint over the whole structure *if the old paintwork is in very bad condition :* complete pickling and painted as for new bridges	on metallized surf (see No. **2.731**) bitumastic paint or chromate paint white zinc paint
National Light Railways Cy (S.N.C.V.) (Belgium)	2 coats of lead or zinc chromate paint 2 coats of oil paint		—
Lower Congo to Katanga Railway . . .	*in the shops :* 1 coat of lead paint *on site after assembly :* 1 coat of lead paint	2 coats of ferrolead 2 coats of aluminium	—
O.T.R.A.C..O . . .	1 coat of lead paint 2 coats of white lead paint		—
D.S.B. (Denmark) .	2 coats of paint → chromate of zinc in sea water districts; → lead paint in soft water districts 2 coats of white lead paint, white zinc or white titanium A 3rd finishing coat of aluminium bronze is often applied The D.S.B. make a wide use of boiled oil paints, in places where it is not necessary for the pa to dry out quickly, and synthetic binders for the paintwork of structures in the open ai order to adapt the drying period to climatic conditions		
R.E.N.F.E. (Spain) .	1 coat of lead paint 2 coats of antirust paint of various brands		none
Finnish State Rlys .	2 coats of lead or iron paint 2 coats of protective paint		none

tions to questions 2.721, 2.722, 2.724 and 2.725.

22. Regulations for preparing surfaces to be protected by painting — *or new bridges*	*(b) for old bridges*	*2.724 Precautions taken to protect surfaces in permanent contact*	*2.725 (a) Average period between repainting*	*2.725 (b) Carrying out partial repainting*
sanding , blow torching, scraping and brushing lts are satisfactory is always more effective than stripping owlamp		a coat of paint not having a lead base on surfaces that will be in contact when assembled in the shops — a coat of linseed oil in the shops and a coat of lead paint immediately before assembly	5 years	—
sanding and pickling		—	—	—
race of rust must be scrupulously removed		—	5 years	no
g, cleaning with wire brush		none	5 years	no
sanding	cleaning, scraping, brushing (with a mechanical brush) exceptionally sanding	1 or 2 covering coats and after erection puttying with lead putty	10 years in the eastern part of the country 5-6 years in the west	for the most exposed bridges, the paintwork is partially made good every summer
g, scraping, brushing ults are not satisfactory		1 coat of lead paint	5 years	only parts that have shifted
areful cleaning of the surfaces by brushing y chemicals		lead based anti-rust paint	15 to 20 years	part repainting is exceptional

Administrations	2.721. Anti-rust paints used : (a) for new bridges	(b) for old bridges	2.723. Special paints used in special circumstances or for trial purpo
S.N C.F. (France) .	*in the shops :* 1 coat (in certain cases 2 coats) of lead paint *on site after assembly :* 2 coats of micaceous iron oxide paint The paint is brushed on	same painting as new bridges	The S.N.C.F. has b to experiment with cial paint in the of certain bridges the sea : chlo rubber, vinylic sy metal lead paint
Chemins de fer Economiques (France) .	as on the S.N.C.F.		none
Algerian Railways . .	as on the S.N.C.F.		none
Cameroons Rlys . .	2 coats of lead paint 3 coats of antirust paint, with fungicide, metallic oxide base, brushed on		none
French West African Railways	as on the S.N.C.F.		none
Djibouti to Addis Ababa Railway . .	2 coats of lead paint 2 coats of antirust paint brushed on		none
Viet-Nam Railways .	1 coat of lead paint 1 coat of white zinc paint or 2 coats of coaltar		—
M.A.V. (Hungary) .	1 coat of red bauxite paint (lenalkid-bauxite) 2 coats of paint The bauxite paint has not given satisfactory results		there is a shortage o in the country in the case of surface ticularly exposed corrosion a first of lead paint is
F.S. (Italy)	*in the shops :* 1 coat of lead paint *on site after assembly :* 1 coat of lead paint 2 coats of white zinc paint brushed on	the pickled areas are repainted with a coat of lead paint and 3 coats of paint 1 coat of lead paint 2 coats of white zinc paint	—

istrations to questions 2.721, 2.722, 2.723 and 2.725. *(Continued).*

2.722. Regulations for preparing surfaces to be protected by painting — *) for new bridges*	*(b) for old bridges*	*2.724 Precautions taken to protect surfaces in permanent contact*	*2.725 (a) Average period between repainting*	*2.725 (b) Carrying out partial repainting*
ing by wire brush scraper	brushing, cleaning and washing old paintwork in good condition scraping, hammering and burning off parts where paintwork is bad exceptionally pickling	surfaces permanently in contact are not painted	5 years near the sea 12 years or even more in mountain districts	
hing with wire brush, sting, washing	scraping, hammering, scaling and brushing	—	10-15 years	partial repainting is done
ing or scraping, brushing, puttying		1 coat of paint	7-10 years	yes
scaling, sanding, brushing		none	8 years	every time the bridge is overhauled
careful scraping		none	varies a lot	every time the bridge is overhauled
scraping and brushing, or sanding		2 coats of lead paint before assembly	5 years	complete or partial repainting according to condition
—		—	4 years	complete or partial repainting according to condition
surface is cleaned down to the metal by echanical means (scraper, steel brush) All ndamaged paintwork is retained. After cl aning is given a coat of lacquer benzine (with linseed il if lead is used)		undercoating is used for the other surfaces	8 years	generally no
ned by scraper and ire brush	scraped, scaled and brushed. The metal must be laid bare wherever the old paintwork is in poor condition	1 coat of lead paint	10 years	partial repainting is exceptional

PLATE 6. — **Résumé of the replies received fro**

Administrations	*2.721 Anti-rust paints used :* *(a) for new bridges* / *(b) for old bridges*	*2.723 Special paints used in special circumstances or for trial purpos*
C.F.L. (Luxemburg) .	2 coats of « Ferriline-Terrobin and Tegacier » anti-rust paint, brushed on, except in inaccessible places where a spray gun is used	the underneath of m bridges exposed smoke from loco tives is treated « Goalyear » li black cement
N.S. (Netherlands) .	*(a)* lead paint, iron-lead paint, undercoat, isolating paint, rubbed *(b)* bitumastic emulsion, 4 coats, sprayed *(c)* bitumastic paint, 3 coats, rubbed in	the N.S. use spe paints for special conditions
C.P. (Portugal) . .	3 coats of paint brushed on	in these cases better q lity paint is used
C.F.F. (Switzerland)	2 coats of lead paint 2 coats of linseed oil paint with metal pigment of extended type (often aluminium) brushed on	the C.F.F. have rece been making trial zinc based paints the results are enc aging
Damas - Hama Railway (Syria) . . .	1 coat of lead paint 2 coats of grey paint brushed on	—
Czechoslovakian Ministry of Transport .	*Bottom coat :* consists of lead based paint (recommended especially for humid areas) or lead and iron oxide base ($Fe^2 O^3$) or alkide resine oil base with a mixture of iron red and 10-15 % yellow zinc pigment 2 covering coats of linseed oil paint with zinc + black pigment for lacquer + baryum sulphur or synthetic enamels composed of the same pigment and an alkide resine or glycerophthalic	occasionally, but v rarely, in particul bad site conditions, and asphalt based b mastic varnishes used, and also chlo rubber varnish
Tunisian Railways . .	2 coats of paint brushed or sprayed on	bitumastic paints for posed bridges in s laden districts
J.D.Z. (Jugoslavia) .	2 coats of lead paint 2 coats of oil paint	none

istrations to questions 2.721, 2.732, 2.723 and 2.725 *(continued).*

2.722. Regulations for preparing surfaces to be protected by painting *) for new bridges*	*(b) for old bridges*	*2.724 Precautions taken to protect surfaces in permanent contact*	*2.725 (a) Average period between repainting*	*2.725 (b) Carrying out partial repainting*
ed by scraper and wire brush wherever the tal has rusted; washed with caustic soda where old paint is still good tionally, sanding		a coat of lead paint to rivetted assemblies; a coat of linseed oil to welded assemblies	5 years	complete repainting of bridges $<$ 15 m part repainting as required of bridges $\geqslant$ 15 m
sanding	de-rusting, de-greasing, sanding	lead paint	5 to 10 years	always complete repainting
ally cleaned by sand jet		a coat of lead paint	4 to 10 years	partial repainting is done
sanding	generally cleaned by hand and with mechanical tools. Sanding when absolutely necessary	a coat of lead paint	min. 15 years max. 40 years	the bridge maintenance gangs touch up any local damage
—		—	—	—
hoslovakian standards CSNI *198-36* (now der revision)		1 coat (rather thicker) of the paint used for the first undercoat	6 to 10 years	if necessary partial touching up or repainting
scaling, scraping and brushing		none	—	—
hed by hammer, steel brush and sand jet		none	5 years	if necessary partial repainting is done

In general the painting of new metal bridges includes :

— one or two layers of ground coat;

— two layers of protective paint.

For the former, a *lead base paint* is generally used.

Other paints used, but more rarely, are :

— *chromate of zinc paint*, which the D.S.B. (Denmark) uses in sea water districts, whilst lead paint is used in districts with soft water;

— *combined lead and iron paint;*

— *red bauxite paint (lenalkid-bauxite)* used by the M.A.V. (Hungary) who, however, are not very satisfied with it, and for this reason to protect surfaces particularly exposed to corrosion are using a lead base paint, which in that country is difficult to get.

— *alkali resine oil paint* with a pigment formed by a mixture of lead with 10 to 15 % chromate of zinc.

In the case of new bridges, the first coat of paint is put on in the shops. Most Administrations (S.N.C.B., D.S.B., Finland, F.S., N.S., C.F.F., J.D.Z.) generally apply a second coat on site after assembly. As regards the protective paint, there is still more variety. White zinc paints predominate, but white lead paint is also used (S.N.C.B., D.B.), white titanium, micaceous iron oxide (S.N.C.F.), aluminium, and other paints, the names of which, but not the composition, are given in the replies.

Two coats of protective paint are generally given. The S.N.C.B., the Cameroons Railways stipulate three coats. A third coat of aluminium bronze is often given by the D.S.B. This coat protects the one under it from ultra-violet rays.

The medium generally used both for protective and other paints is pure boiled linseed oil. Different mediums are mentioned by :

— the D.S.B. who, where rapid drying is not necessary, use a mixture of boiled oils, but use synthetic mediums for the paint used on bridges in the open air in order to adapt the drying time to the climatic conditions;

— the Czechoslovakian Railways who use either linseed oil paint, or alkali resine oil paint, or synthetic enamels with an alkali or glycero-phthalic base.

Bitumastic or coal tar paints are also used for protective paints with the addition of slaked lime in the proportion of 2 or 3 %, or Portland cement in the proportion of 3 to 5 % added hot.

Nearly all the Administrations state that the paint should be brushed on, and not sprayed.

The C.F.L. allow spraying to be used only for parts difficult to get at; the S.N.C.B. only allow it in the case of the coats given in the shops, on condition the paint is not thinned down; the D.S.B. in the case of protective paints; the Tunisian Railways : it would appear from their replies, allow spray guns to be used in every case.

The paints used for old metal bridges are generally the same as those used on new bridges. Many Administrations in their replies made no distinction between the two. Generally, when repainting, the first coat is restricted to those surfaces where the metal has been revealed by stripping off the old deteriorated or flaking paint.

2.722) *What regulations are in force as regards the preparation of the surfaces to be protected by painting in old and new bridges? Are these regulations satisfactory?*

The care given to the preparation of the surfaces is of great importance for good results when painting. In the case of new bridges, the most effective method is sandblasting, which is used in most cases : by the S.N.C.F., the D.S.B., the N.S., the C.F.F. and sometimes by other Administrations.

In general, in the case of old bridges, sandblasting is only used when they are in a really bad condition, i.e. when it is necessary to strip off the old paint completely. In other cases, it would not be advisable to sandblast, as it would be difficult to avoid damaging the old paintwork that was still in good condition.

Many Administrations, either for new bridges, or for old bridges (and nearly always in the case of these latter), when preparing the surfaces to be protected by paint, clean them carefully by hand or by mechanical means.

The practice does not differ materially from one railway to another. The object is to remove all deposits and stains on the surfaces where the paint is still in good condition, to strip down to the metal where corrosion is seen to be beginning, and finally to remove the old paint completely wherever it is cracking or flaking. To do this the paint is scraped, chipped or hammered, and sometimes burnt off where it is in bad condition and cleaned with a metal brush. The surfaces where the paint is still in good condition are washed with lye or soda and brushed. The results of such work, if it is carefully carried out, are generally satisfactory.

The R.E.N.F.E. alone report the advisability of still stricter regulations both for the preparation of the surface and for the actual painting, and states that they are not yet satisfied with the results obtained.

2.723) *Is any special painting done in the case of bridges in special positions?*

The replies received show :

— In most cases, it is not possible to speak of real special paints, but one or other of the paints habitually used are selected according to the particular conditions of the site.

— We have already pointed out, for example, that the D.S.B. make use of two different paints for sea water districts and soft water districts, and that the M.A.V. used lead paint on bridges were conditions are particularly difficult. Under these conditions, the Czechoslovakian Railways use tar and asphalt paints. The Tunisian Railways use bitumatic paints in salty areas. The S.N.C.B. uses zinc chromate paint for the protective coats on metal surfaces for which it forbids the use of lead paint, which are on the contrary used in other cases, either for the paint (lead) or the protective paint (white lead).

— Tests of so-called special paints, i.e. different paints from those used to date, have begun on the S.N.C.F., who are using near the sea paints with a vinylic resine base, metal lead and chloritic rubber.

— Chloritic rubber paint has been used in particularly bad conditions by the Czechoslovakian Railways (and also by the F.S.) but so far not on the bridge structures.

— The C.F.L. (Luxemburg) to protect the lower parts of bridges exposed to the smoke from locomotives, uses a system of treatment with « Goodyear » liquid black cement.

2.724) *What precautions are taken to protect surfaces permanently in contact?*

There was a remarkable diversity in the replies to this question. Certain Administrations stated that they did not take any precautions. Amongst these is the S.N.C.F. which states :

« Surfaces permanently in contact are not painted. They are not the object of any special precautions, except that the riveting regulations must be respected, which are fairly strict in order to assure the tightness of the assembled part, the spacing of the rivets being limited to 5 diameters on the sides and 7 diameters at the top. »

The F.S. also for some years built bridges on which surfaces permanently in

contact were not painted, but the results were not satisfactory, so that they have begun to paint such areas with a layer of lead paint, before they are rivetted together. The C.F.L. include amongst defects in making bridges, which may be the cause of deterioriation, the fact that surfaces in permanent contact with steel were not protected.

The S.N.C.B. put a layer of lead-free paint on surfaces to be rivetted in the shops; and a coat of iron oxide in oil in the shops and a coat of lead paint immediately before assembly in the case of surfaces to be rivetted on site.

2.725) *What is the average period on your railway between two paintings? Do you make any distinction between touch up or partial painting and a complete repainting?*

The replies to this question demonstrated the effects of the locality on the life of the paintwork. The average period between two successive repaintings is about 5 years in places very near the sea, or in markedly industrial regions, or in countries with a humid tropical climate; it may be 10 years under ordinary conditions, and according to the C.F.F. may even be as much as 40 years in the mountain regions where the air is particularly pure.

The Administrations, who have to repaint at short intervals, do not proceed to make a touch-up or part repainting, but take care to restore the protective paintwork completely.

The D.S.B. forms a very interesting exception to this rule, since each summer they partly repaint certain bridges in the most exposed positions in the west of the country, thereby managing to increase the period between complete repaintings to 10 years.

When there is a very long interval between two complete repaintings, it is necessary to do some touching up, which is often done during the periodical maintenance work necessary on metal bridges.

* * *

The method used on the Upper Congo to the Great African Lakes Railways must be specially mentioned. This Administration carries out continuous maintenance of its bridges « which are very regularly inspected by the section foremen who have gangs of native labourers under their charge. » Any signs of rust are immediately scrapped off and tarred. Places difficult of access are filled up with hot liquid tar.

2.726) *Have you observed any marked differences in the way the paintwork stands up on different bridges close to each other? If so, have you found it possible to decide for what reasons?*

Most Administrations replied in the negative to this question.

Certain Administrations (Algerian Railways, N.S., C.F.F.) replied that they have noticed differences in the way the paintwork stands up even on bridges very close to each other, but that the reason for this must be attributed to the varying degree of care with which the cleaning was done, or the different quality of paint.

According to the S.N.C.F., it cannot be said that there are any great differences in the way the paintwork of different bridges close to each other stands up, but there are differences even in different parts of a bridge itself. They are not very great, however, and are generally due to differences in the amount of sun or humidity. For example, the end spans of large bridges over rivers or on the banks are generally in a worse state than the central spans, as these get more air and therefore are less exposed to humidity. The Czechoslovakian Railways, the Djibouti to Addis Ababa Railway and the F.S. on the contrary have noticed cases in which the difference in the atmosphere and exposure to sun have led to very marked differences in the way the paintwork stands up.

2.727) *Have you encountered any special difficulties in assuring the proper conservation of the paintwork of watertight decking? If so, do you think special constructional arrangements could prevent or retard the damage?*

A great many Administrations did not reply to this question, or else replied that there were no water tight deckings with a steel plate covering on their system. Only the Czechoslovakian Railways replied that they have not found any special difficulty in assuring the proper conservation of the paintwork of watertight decking.

According to the replies received from the other Administrations it is obvious that a distinction must be made between watertight decking without ballast and watertight decking with ballast.

In the case of watertight decking without ballast, there are no more difficulties than usually involved in the maintenance of the flooring (S.N.C.B.), maintenance which must be very carefully carried out (S.N.C.F.).

In the case of watertight decking with ballast, difficulties may occur in the maintenance of the parts carrying the ballast, and difficulties in connection with the maintenance corresponding to the assembly of these parts with the main beams and cross stays.

If the ballast is carried directly by pressed steel plates, it is difficult to protect the upper surfaces of the plates in contact with the ballast or the underside where there is heavy condensation from corrosion.

The C.F.F., who state moreover that they are lacking in experience on this point, say that ordinary linseed oil paint is not suitable for these plates, but tar, chloritic rubber or synthetic resinous paint must be used.

The S.N.C.B. generally metallize the sheets of the flooring and as we have already said, paint them with a layer of tar (or with a first coat of zinc chromate paint and a second coat of white zinc paint.

The M.A.V. use steel with 4 % copper for these plates. They protect the upper sides of them with a special coat of bitumatic paint, whilst the underside is painted with ordinary paint.

Although *there is a great deal of difficulties* in protecting the plates against corrosion, there is still more serious deterioration in the parts where the plates are fastened to the main beams or cross members, unless care is taken to make the construction rational (see 2.51 *d* and 2.54 *f*).

The S.N.C.B. has noted in this connection that the fastening of the plates to the web of the beams by means of an angle is particularly bad. The paint only lasts a very short time, and corrosion can lead to serious deterioration, or even to the complete destruction of the assembly (see fig. 5).

The S.N.C.B. find that when the height of the structure makes it possible, it is better for a watertight decking to be obtained by using a concrete deck covered with a watertight covering. The arrangement used in this case is shown in figure 6.

The S.N.C.B. stress the importance of taking the greatest care in assembling the decking with the metal components in order to avoid corrosion at these points.

The D.S.B. state that at the present time they always use reinforced concrete containers for the ballast.

The C.F.F. point out the need for having the decking really watertight, otherwise the resultant lime laden water spoils the paintwork of the metal components.

2.728) *In a more general way, do you think you can suggest any variation in the usual constructional arrangements which would encourage the proper conservation of the paintwork?*

Most of the Administrations did not answer this question, and others stated that they could not suggest any variation.

The R.E.N.F.E., the « Chemins de fer Economiques », the Algerian Railways, the C.F.F. and the Czechoslovakian Railways quote the regulations which must be obeyed in designing a metal bridge.

The structure must be as simple as possible. Main girders with full web are better than trellis girders. The construction must be well ventilated. Assemblies and sections forming a trough must be avoided as well as parts difficult of access.

According to the C.F.L. and the C.F.F., welding is a step forward.

The C.F.L. advise the adoption whenever possible of standard rolled beams with wide flanges instead of composite beams.

According to the C.F.F., bridges with continuous ballast are better protected than open bridges.

The Algerian Railways recommend flanging the drain holes to protect the undersides of the floor plates (see 2.58).

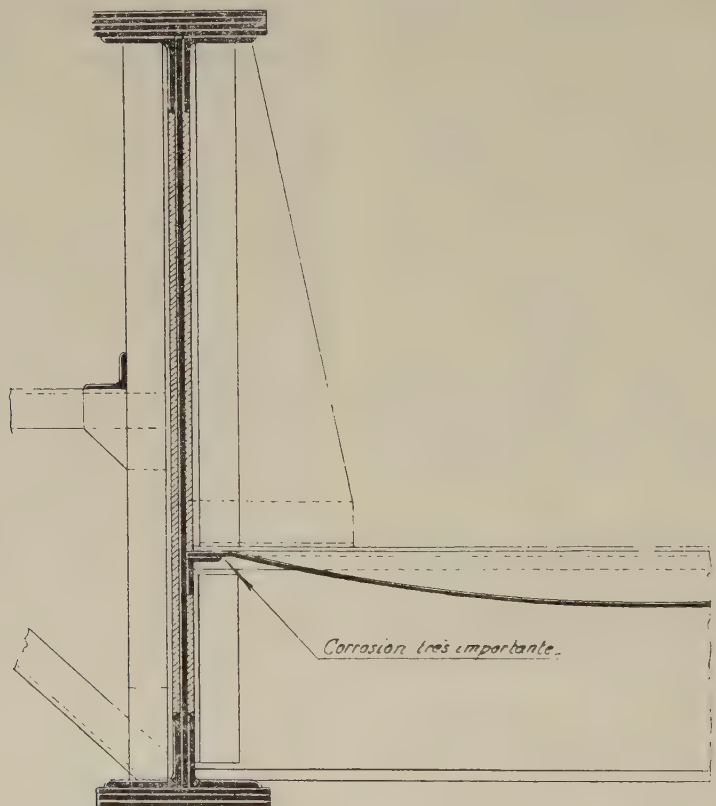


Fig. 5. — *S.N.C.B.* : Corrosion in line with the fastening of the sheets to the webs of the beams.

N. B. — Corrosion très importante = very important corrosion.

2.729) *Are bridges repainted at non-predetermined intervals, based solely on the state of repair of the bridge, or is it carried out according to a definite cycle established once for all?*

Repainting is carried out according to

a definite cycle on the R.E.N.F.E. (every 5 years), the French West African Railways (every 5 years), the Viet-Nam Railways (every 4 years), the Hungarian Railways (every 8 years), and the Portuguese and Jugoslavian Railways (every 5 years).

Metallization is used above all by the D.S.B. and the S.N.C.B.

The S.N.C.F. have recently done some metallization. The C.P., N.S., and C.F.F. have made certain trials.

The S.N.C.B. have used metallization for the metal parts of bridges which are no

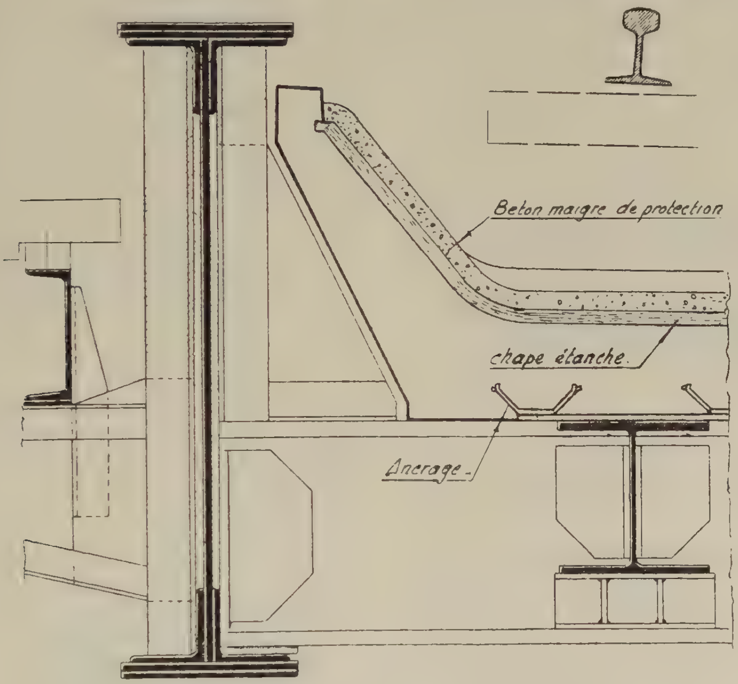


Fig. 6. — *S.N.C.B. :* Type of watertight decking.

N. B. — Béton maigre de protection = protecting concrete. — Chape étanche = watertight casing. — Ancrage = anchoring.

longer accessible after assembly, for example the end parts, near the protective walls and the upper sides of the flanged plates of the decking.

The D.S.B. have used metallization on a much larger scale, even for whole bridges.

The S.N.C.B. generally uses the Schoop method (projection of liquid zinc). This operation is normally carried out in the shops, but at the present time the S.N.C.B. is using it on the work site at any rate for the cover-plates above the decking plates, as these are rivetted on site and

The Portuguese Railways state that they have different cycles on their different systems.

All the other Administrations base the date of repainting upon the condition of the paintwork.

2.731) *Have you used metallization? If so, what method have you chosen amongst those known? What results have you obtained? Do you apply one or more coats of paint after metallization?*

the rivets spoil the metallization if this has been previously applied.

The D.S.B. use a spelter bath for small components and spray on the zinc in the case of large components.

The D.S.B. and the C.F.F., who have made trials with both the spelter bath and spraying on the zinc, report that the layer of zinc obtained by the latter means is less dense, and it is harder to get it even.

Consequently, the D.S.B. immediately carry out the painting of surfaces that have been metallized by spray gun, whilst the parts that have been metallized in the bath, if not particularly exposed, are not painted until the layer of zinc shows signs after several years that it is beginning to deteriorate.

The metallized surfaces are painted on the D.S.B. with a coat of zinc chromate paint and one or two protective coats.

The S.N.C.B. generally uses bitumastic paint for the decking plates, and if a further coat of paint is needed, they use a zinc chromate paint for the first coat, like the D.S.B. and a white zinc paint for the finishing coat.

The S.N.C.F. report that one bridge was metallized with aluminium in the shops, and touched up on site after assembly.

The method used is the METCO method (spraying on the metal obtained by fusing a metal rod) after which two coats of vinylic paint containing powdered aluminium are sprayed on.

This work has only been done very recently, so the S.N.C.F. cannot draw any conclusions as yet.

2.732) *What arrangements have you adopted as regards the preparation of the surfaces to be protected?*

The surfaces to be protected by the spelter bath are pickled chemically (D.S.B., C.F.F.).

Surfaces that are metallized by spray gun have to be very carefully sanded. They must be really clean if good results are to be obtained (S.N.C.B., S.N.C.F.).

2.74) *Have you used or considered using other methods of protection? If so, please give a detailed description and state the results obtained.*

The S.N.C.B. and S.N.C.F. for some time have encased components in concrete or cement as a protection against corrosion.

The arrangements adopted are extremely varied. Mention may be made of the use of prefabricated concrete or eternite components to protect the bottom chord members.

Plate 7 shows some of the devices adopted by the S.N.C.B. and S.N.C.F.

The S.N.C.F. points out that the connection between the concrete and steel must be given very great care or the result will be a failure. This appears to advise against filling in inaccessible hollows between metal components as is done on the S.N.C.B., and which the F.S. have tried with disappointing results.

2.75) *Have you been led to use, at least to some extent, rustless steel or other metals or alloys in order to avoid corrosion of the component parts of the structure?*

The D.S.B. have used chrome or copper steel for some of the most important of their bridges and stipulated steel containing 3 to 0.6 % copper in the case of the bridge over the Little Belt; and steel containing 0.25 to 0.5 % copper and 0.7 to 1.1 % chrome for the bridge over the Storstrommen, without, however, reporting that the use of such alloys has resulted in any benefits as regards maintenance.

The S.N.C.F. formerly made some trials with steel containing copper, but only on a small scale which circumstances prevented them from continuing, and no definite conclusions could be drawn from the results obtained.

The M.A.V., as we have already said (No. 2.777) use steel containing 0.4 % copper for the plates of watertight decks with ballast, with satisfactory results.

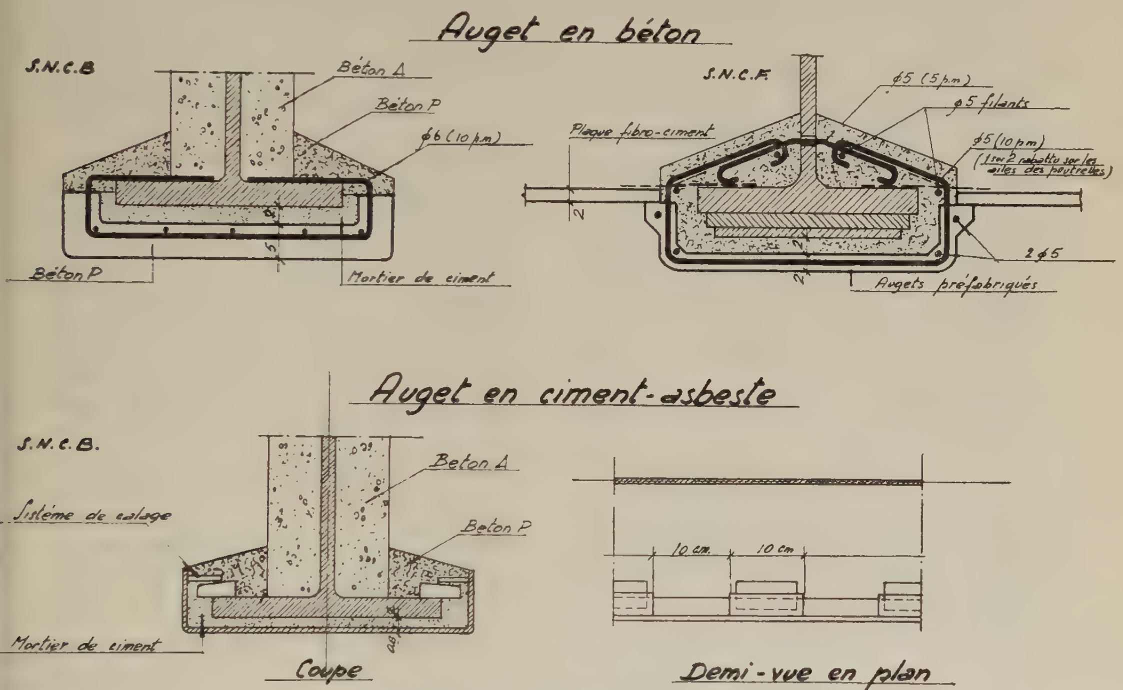
No other Administrations have used rustless steel, or other metals or alloys, to prevent corrosion.

The S.N.C.B. merely stated : « it is not possible to give any rules for such repairs, as each case must be decided on its merits ». The F.S. gave a similar reply.

The S.N.C.F. stated : « the damage observed in old metal bridges can generally be blamed on the poor design or errors in manufacture (webs not flush with the angles, rivets pulling out, etc.) and an attempt is made to remedy such defects when replacing the damaged components ».

Other Administrations (Light Railways, Viet-Nam Railways) merely state that « particularly bad parts are replaced »;

PLATE 7. — *S.N.C.B. and S.N.C.F. : PREFABRICATED TROUGHS TO PROTECT THE BOTTOM CHORD MEMBER OF METAL BEAMS.*



Explanation of the French wording :

Auget en béton = concrete trough. — Béton = concrete. — Mortier en ciment = cement mortar. — Plaque fibro-cement = fibre-cement plate. — Filants = wires. — 1 sur 2... poutrelles = 1 out 2 turned down on to the flanges of the beams. — Augets préfabriqués = prefabricated troughs. — Auget en ciment-asbeste = asbestos-cement trough. — Système de calage = method of wedging. — Demi-vue en plan = half view in plan.

2.81) *What methods do you use for the repair of metal bridges showing defects due to ageing? Have you any particularly interesting cases to report?*

The replies to this question were very brief.

whilst other Administrations add that if it is not possible to replace such parts, they are reinforced (Cameroons Railways, C.F.L.).

The Portuguese Railways replace the material or alter the structure to improve its characteristics when the steel is in good condition.

The C.F.F. reply that they have not come across any defects due to ageing.

The R.E.N.F.E. make use of welding (see 2.82).

The D.S.B. replied that in general they use the ordinary classical methods. They report however as an exceptional case the method used to repair the bascule bridge over the Limfjord, damaged during a collision (see No. 2.42).

As we have already stated under No. 2.42, the most serious damages to the bridge were: appreciable deformation towards the inside of the end of the bottom chord member which was directly hit, and the breaking, due to fragility, of the top chord member immediately above the place of collision. Another break of this sort was also found in a windbracing rail. The whole bridge had suffered lateral displacement and had rotated around its longitudinal axis. When lowered again after the collision, the bridge was no longer able to return to the true horizontal position owing to the deformation it had undergone.

After careful examination of the deformation to the bridge, it was decided to repair it on site, except for the part of the bottom chord member that had actually been hit, all the deformation suffered by the other chord members was below the elastic limit, and for this reason they did not have to be replaced.

The first repairs were to assure the continuity of the top chord member by temporary coverplates. Then a temporary beam was put transversally to the fixed span (to the south of the bascule bridge) to support the counterweight; at the same time two hydraulic jacks were inserted under the free end of the bascule bridge to support it. In this way, the main beams of this span were freed from all stresses due to outside loads, and were simply supported at their ends.

Then temporary chord components were introduced, over three consecutive panels, exactly besides the damaged one, and to obtain exact correspondence between the distance between the ends of the panels, and the length of these chord components, a hydraulic thrust cylinder was put horizontally against the damaged chord member. All the time by means of thrust cylinders, this time acting transversally, the bent top chord member was gradually restored to its proper position.

During these repairs the lower windbracing assemblies were temporarily unfastened and some of the cross piece assemblies with the cross stays. By means of jacks it was possible to restore the span to its initial position without exerting any dangerous pressure upon it. The damaged part of the bottom chord member was replaced, and the break in the top chord member mended by a joint plate. (For more detailed information see No. 52 of the 24.12.1955 of the review: *Ingenioren* — Ugivet af Dansk Ingeniörforning).

2.82) *What has been your experience as regards welding in repairing or strengthening steel bridges?*

Some Administrations, amongst them the M.A.V. (Hungary) do not generally use welding.

The S.N.C.B. has never used welding to repair or strengthen steel bridges. This statement should be noted as the Belgians have been the pioneers of welding.

The D.S.B. are very cautions in using welding for strengthening bridges, since the steel used for their construction generally does not lend itself to welding.

The F.S., in general, only allow welding to be used in repairing secondary bridges. During the war, however, and even in the immediate post war period, it was used even when repairing important structures

(in one case two sections of spans with twin main beams were welded at the head) and the repairs were even carried as far as replacing whole bridges. The F.S. do not allow welding in the case of bridges made of puddled iron.

The Finnish Railways have used welding on bridges of more recent construction, to repair war damage. Repairs made in this way have stood up well so far.

Only in exceptional cases have the Czechoslovakian Railways used welding to strengthen or repair old bridges, for example to repair shell holes in the webs of beams, etc.

The Czechoslovakian Railways also state that welding has not given good results when used for repairing bridges made of puddled iron but they mention cases where welding can be carried out without any drawbacks provided suitable precautions are taken.

The N.S. report that their experience of welding in not unfavourable, but welded joints subjected to fatigue have not stood up to it.

According to the opinion of the C.F.L., welding can be recommended for strengthening isolated parts of metal bridges.

The experience of the C.F. with mild steel is in general good provided the elementary rules in this matter are respected (for example, not reinforcing a rivetted assembly by welding) and provided welding is avoided in areas of heavy segregation.

The C.F.F. are less satisfied with the results obtained with puddled iron, where in many cases the iron has cracked under the action of the shrinkage due to the welding.

The Jugoslavian Railways in the rare cases in which they have used it, and the Portuguese Railways, who have often used welding, state that they have obtained satisfactory results.

The R.E.N.F.E. has also used welding apart from repairs to particular bridges and to replace rivetted assemblies with runs of welds, even to reinforce about 30 bridges with satisfactory results.

Whilst as we have already said the D.S.B., the F.S., the Czechoslovakian Railways and the C.F.F. do not recommend welding on puddled iron bridges, in France a great many iron, mild steel and semi-hard steel bridges have been repaired or strengthened by welding since 1928 by the former companies and by the S.N.C.F. since 1938, as well as the « Chemins de fer Economiques ».

Welding has sometimes been preferred to rivetting owing to the conditions under which the work can be carried out. To strengthen bridges in particular, it makes it unnecessary to remove the existing parts; the old companies and since then the S.N.C.F. have been encouraged in this practice by the very satisfactory results obtained right from the start.

The S.N.C.F. reports that the repairs are made :

— either by superimposing a new component on the old defective component, when it is not possible to cut it out or remove it;
— or, preferably, by substituting a new component for the defective component which has previously been cut out or removed (this substitution may be of a mere piece of sheet some few decimetres square or complete chords of beams, including the web, corner angles and bearing plates);
— or by joining together by welding, without the addition of any new parts, of whole sections (in the case of bridges cut up by the military during the war).

On the S.N.C.F. system, repairs to railway bridges alone cover a total length of about 1 145 m of double track bridge.

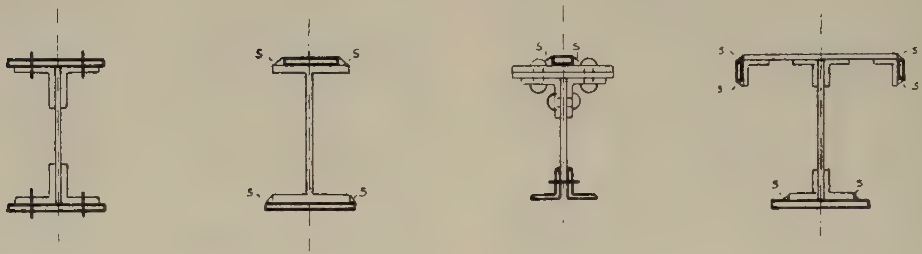
It must be added that repairs to numerous overbridges (replacing the bottom chord members of beams which have been partly or completely destroyed by smoke above the railway line).

Only old iron underbridges have been strengthened by welding.

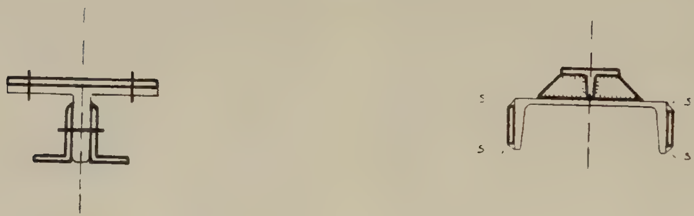
The chord members of beams have been

PLATE 8. — *C.F.F. : EXAMPLES OF REINFORCING.*

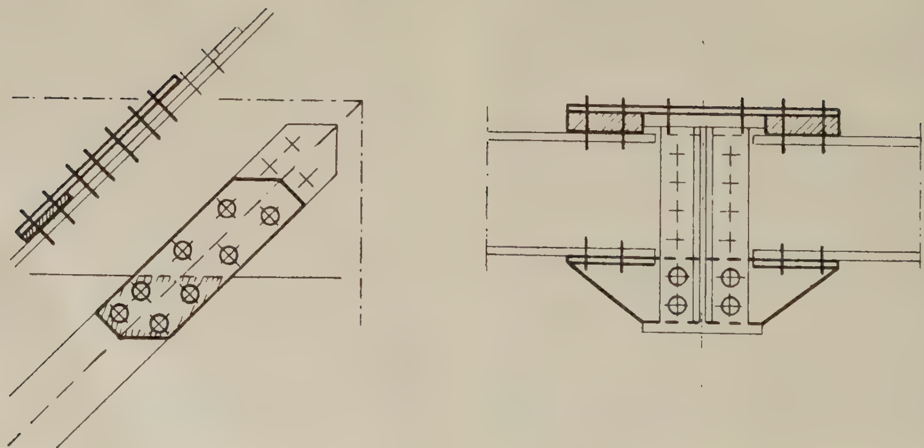
a) Stringers, cross stays, chord members.



b) Diagonals.



c) Joints, fastenings.



strengthened by adding square or U irons to the rivetted bearing plates, housed between the rows of rivets or fixed along the edges.

Trellis girders are strengthened by adding a flat iron across the existing flat iron to form a T, or by adding other thin trellis bars between the existing ones, or sometimes by inserting sheets between the webs of the beam, thus turning it into a full web beam. The fastenings of the trellis bars are strengthened by additional pieces welded at one end to the existing trellis and at the other to the chord member of the beam.

A total length of approximately 950 m iron bridges with one or two tracks have been reinforced by welding in this way.

The S.N.C.F. report further that all repairs to steel, as well as most of the repairs or reinforcements to iron, have been carried out without any special difficulty, and have proved perfectly satisfactory.

To obtain such good results certain fundamental rules have been respected, viz. :

a) avoid as far as possible locked in internal stresses of the bridles (bridage) in the welds. The new parts are therefore generally welded freely at one end, and the other end is fastened by riveting;

b) in the case of iron bridges, design the reinforcement and adopt a welding technique which will avoid laminating the metal.

The importance of the reply received from the S.N.C.F. is obvious, as is the contrast between the results obtained by the S.N.C.F. and other Administrations.

2.83) *Can you give any examples of particularly interesting recent strengthening work carried out in order to eliminate constructional defects?*

Very few Administrations answered this question, and amongst those who did, the Portuguese Railways merely reported the work done on the Maria Pia bridge over the Douro at Oporto, without giving any particular details.

The S.N.C.B. report the following works :

— Addition of new cross stays thus reducing the length of the stringers and improving the stability of the main beams;
— Laying cross-diagonals in the main trellis girders;
— Fixing of chairs under the longitudinal girders and the cross stays.

The S.N.C.F. reports the following reinforcement carried out by welding according to the rules specified in the previous reply :

On a bridge over the Adour at Bayonne (*Revue Générale des Chemins de fer*, October 1953) the webs of the bridge components consisting of very offset trellis girders were replaced by full plates cut in such a way as to reduce to the maximum possible interruptions to the traffic and the work on the site.

The strengthening of the multiple trellis work of certain long beams has also been done by welding. The strengthening of this trellis is so designed as to do away with any offset, whilst increasing the stiffness. The S.N.C.F. state that for reinforcements of this kind, the use of welding makes it possible to simplify the assemblies to a certain extent and the work on the site. Even the Light Railways Company has carried out similar reinforcements to trellis girders.

This latter company also mentions amongst the work undertaken to remedy defects in design the fitting of horizontal gusset plates making it possible to encase the stringers and cross stays.

The C.F.F. report that in the case of rails fastened directly to the stringers grooved rubber plates and bearing plates 5 to 12 mm thick have been inserted.

2.91) *Have you had to strengthen any metal bridges in order to enable heavier loads than those originally calculated to be carried?*

PLATE 9. — **Résumé of the replies received from the Administrations to questions 2.91 and 2.92.**

Administrations	*Question 2.91*	*Question 2.92*
S.N.C.B. (Belgium)		Generally bridges that have to be strengthened are already very old, nearly always made of puddled iron. Their replacement is to be recommended.
Belgian National Light Railways (S.N.C.V.)		It is considered of value to carry out reinforcement in order to allow heavier loads to be taken.
Lower Congo to Katanga Railway . .	In 1951, the stringers and cross stays of five old bridges (1914) were strengthened by riveting on additional bearing plates.	Yes : the cases that had to be solved only required the strengthening of certain parts, so that economically it was advisable.
O.T.R.A.C.O. Matadi-Leo Railway	An intermediate support was added under each main beam with full web on the Belgika bridge. Jacks were used to make contact and take the load on the new pile.	It is more economical to strengthen if possible, especially in the case of a bridge in good condition.
D.S.B. (Denmark) .	The D.S.B. have carried out work to strengthen bridges. During this work the old bridge must be so carefully shored up that it is subjected to as few stresses as possible.	It is not possible to give any general reply to this question. The question of the ageing and fatigue of the steel is of primordial importance.
R.E.N.F.E. (Spain)	Recently all the bridges between Santa Cruz de Mudela and Baera (Madrid-Seville line) were reinforced by welding.	The R.E.N.F.E. thinks that reinforcement is advantageous when the bridge is made of steel and when the materials added for reinforcement do not increase the weight of the old bridge by more than 2 %.
Finnish State Railways	The decks of old bridges have been strengthened so that they could be used by heavier loads when the main beams were sufficiently strong.	A 100 m long bridge whose bridge components were strengthened has been in service for about 25 years since it was strengthened. Consequently there is no doubt that it was advantageous.
S.N.C.F. (France) .	Reinforcement to allow of heavier loads is the current practice on the S.N.C.F. This is often done by reinforcing the inadaquate parts by new parts joined to them by welding or rivetting. Sometimes, it is advisable to use reinforced concrete to increase both the strength and the rigidity of the bridge. Encasing in concrete can be done completely or limited to the parts under compression. In certain cases, it is advantageous to replace parts that are too weak by entirely new parts.	The choice between replacing or strengthening is guided either by a comparison of the cost involved or by consideration of the facility with which the work can be done and which will cause the least upset to the traffic whilst being done. Such an investigation, at once financial and technical, usually leads to adopting the solution of replacement for small bridges and reinforcement for large bridges.
Chemins de fer Economiques (France)	Most of the old bridges on standard gauge lines have been strengthened. This is generally done by adding bearing plates or angles to the inadequate components.	Same opinion as the S.N.C.F.

ATE 9. — **Résumé of the replies received from the Administrations to questions 2.91 and 2.92** *(continued)*.

Administrations	*Question 2.91*	*Question 2.92*
Algerian Railways .	In particular reinforcement has been undertaken in the case of certain bridges built for metre gauge lines in order to fit them for standard gauge lines.	Reinforcement is generally more economical than replacement for bridges of more than 10 m span approximately, and the saving increases with the span. In general, it is the cost which determines the choice.
Cameroons Railways	Yes : reinforcing the centres by corner plates, adding flats and angles fastened by rivets.	The choice between strengthening and replacing must be determined by the cost.
Djibouti to Addis Ababa Railway . .	All the bridges between Djibouti and D. Daona (311 km) have been strengthened. The reinforcement consisted in adding additional bearing plates and stiffeners. Assembly was by rivetting.	Strengthening is only advantageous if it costs not more than 50 to 60 % of a new bridge.
Viet-Nam Railways.	Reinforcing work has be done.	The age of the bridges on this railway varies between 20 and 40 years. The proportional cost of reinforcement compared with a new bridge is generally 30 %. Reinforcement is always more advantageous.
French West African Railways	The reinforcement consisted of changing the bearing plates or increasing their number. This is work which has to be done in the shops, or on site if the bridge can be dismantled.	In general, strengthening is more advantageous wherever the bridge can be replaced while the work is in progress.
M.A.V. (Hungary).	Formerly, bridges were strengthened by adding new parts to inadequate parts, or by adding a third beam or inserting a new support, etc. Most of the old bridges were destroyed during the second world war. Today strengthening on site is limited to certain components of the old bridge (above all stringers, bridge components and their fastenings or windbracing).	The strengthening of a complete bridge is only economical when this extends its life for 30-40 years. This would not be the case with the old bridges left after the war which are not suitable for reinforcing. Local reinforcement of isolated parts does not take much new material. Such reinforcing is economical even if the bridge will only last a few more years. In general, no precautions have to be taken to assure proper solidarity between the old and new parts, as the stresses in the parts to be strengthened are always very small.
F.S. (Italy)	The F.S. formerly (1905-1915) carried out general reinforcements (adding an arch over the main beams, adding a third beam in overhead bridges, doubling the main beams, reinforcing the stringers, cross stays and fastenings). More recently they have carried out limited reinforcements (cross stays, windbracing, fastenings).	Bridges built since 1905 can generally take the present loads. The F.S. do not consider it advantageous to reinforce generally the more ancient bridges still in use since these are nearly all made of poor quality puddled iron.

PLATE 9. — **Résumé of the replies received from the Administrations to questions 2.91 and 2.92** *(continued)*

Administrations	*Question 2.91*	*Question 2.92*
C.F.L. (Luxemburg)	No.	If the metal bridges are large ones, it is advantageous to strengthen them, the cost being lower than that of replacing them, and railway traffic not being interrupted. In the case of small bridges, replacement is best.
N.S. (Netherlands).	In the case of the bridge over the Lek at Culemberg, the deck was strengthened by welding on plates.	If the construction makes reinforcement possible, yes, but this is hardly ever so. It is therefore better to replace the bridge by a new one.
C.P. (Portugal) . .	Yes.	Yes, as soon as it is found that the weight of metal to be added is less than 20 to 25 % of the weight of the bridge in question.
Czechoslovakian Railways.	Two similar bridges of 42 m span made of multiple trellis girders have been reinforced (with dissymmetrical bars and non concurrent) with insufficient transversal stability. On one of these bridges, the chord members of the main beams were strengthened and an adequate windbracing made arranged along the plan of the bridge. On the second bridge, an intermediate pile was made and the central diagonals were reinforced.	Old bridges can be strengthened provided their condition and constructional design lends itself thereto. Reinforcement is advantageous when for a relatively low expenditure it is possible to obtain an important increase in the carrying capacity of the bridge and the cost is not more than 30 % of that of a new bridge.
C.F.F. (Switzerland)	All the pre-1912 railway bridges of the C.F.F. have been strengthened in the most diverse ways, for example : Adding a truss, or an upper arch, or doubling the main beams, turning a flexible arch into a trellis arch by adding diagonals, adding a concrete deck. Strengthening the stringers, cross stays, chord members, and diagonals by rivetted or welded parts, reinforcing the fastenings and centres.	In principle, the C.F.F. decide in favour of reinforcement when the annual cost occasioned thereby is lower than the annual cost of a new bridge (taking into account the value of the probable life of the reinforced bridge and a new bridge). As a general rule, the C.F.F. consider that reinforcements are only of value when of limited extent, when they can be carried out under good conditions, and if the condition of the bridge gives a reasonable expectation of life.
Tunisian Railways .	Most of the bridges have been strengthened. In general, the work consisted of surrounding the existing bridge by a second bridge connected to the original metal bridge by corner plates, sheets and trellis. More recently in the case of other bridges, the chord members have been strengthened and the trellis replaced.	The Tunisian Railways consider that it is more advantageous to carry out reinforcement in the case of long bridges so as not to have to interrupt the traffic. Small bridges, up to 5 m span are replaced whenever local conditions made it possible by reinforced concrete bridges.
Jugoslavian Railways	No.	In view of the age and condition of maintenance of the bridges on the system the possibility of strengthening them has not even been considered.

If so, please give a brief description of the work done and state what precautions were taken to ensure solidarity between the old and new components.

(The replies to this question and the next one are summed up in Plate 9).

It may be stated that nearly all the Administrations replied in the affirmative to this question. The exceptions were: the Belgian National Light Railways, the C.F.L., the Jugoslavian Railways and the S.N.C.B. We note however that in replying to the previous question, No. 2.81, the S.N.C.B. reported work undertaken to reinforce bridges such as the laying of new cross stays and cross-diagonals in the trellis girders, work which can be understood to be undertaken not only to eliminate defects in the design but also with the object of allowing heavier loads to be carried.

The arrangements adopted to strengthen existing bridges can be divided into two groups:

a) addition of new components;

b) strengthening the sections of existing components.

Fig. 7. — *C.F.F.* : Bridge over the Kerstelenbach. — St. Gothard line; km 47.945; 2 × 50 m span. — Reinforcement by truss.

The work done under the first heading is generally done to strengthen the main beams.

Amongst these we may mention:

a. 1) *the construction of intermediate supports and the reinforcement of the components design to resist shear corresponding to these new supports.*

This measure had been adopted by the Czechoslovakian Railways in the

case of a multiple trellis girder bridge with a span of 42 m, and by the O.T.R.A.C.O. in the case of a bridge with main beam with full web. It was formerly used by the M.A.V.;

a. 4) *adding a truss under the main beams.* Figure 7 shows an example of this method (C.F.F. : bridge over the Kerstelenbach-St. Gothard line, span 2 × 50 m);

Fig. 8. — *C.F.F. :* Bridge over the Linth Canal at Weesen. — Zürich-Coire line, km 31.888; 49.60 m span. — Reinforcement by an arch.

a. 2) *the insertion of a third main beam between the other two in the case of overbridges.* This arrangement was formerly used in Hungary and Italy. In this way, the main beams can be relieved of part of the overload by the third beam, and at the same time the cross stays are also given a third central support;

a. 3) *doubling the number of main beams by laying a new beam alongside each old beam.* This method is widely used by the S.N.C.F., the F.S., the C.F.F. and the Tunisian Railways;

a. 5) *adding an arch springing from the lower chord member of each main beam.* This arrangement has been used by the C.F.F. (fig. 8);

a. 6) *adding an arch springing from the end of the upper chord members.* This arrangement was used by the F.S. in about 1910 to strengthen 10 spans of 30 m (fig. 9);

a. 7) *turning a flexible arch into a trellis arch by combining it with the beam above, carrying the floor, by adding diagonals.* This method has been used by the C.F.F. (fig. 10);

a. 8) *adding a concrete boom.* The C.F.F. report having used this method to strengthen several road bridges. But even if the other Administrations do not report this particular method in their replies to this question, the replies given to the previous questions suggest that they also (amongst them the S.N.C.B.) make use of this method. The S.N.C.F. not only adds a concrete boom, but on many old iron bridges whose too thin components get deformed under overloads, they have encased all or some of the stressed parts in concrete.

Fig. 9. — *F.S. :* Reinforcement of main beams by adding an arch springing from the end of the top chord members (1905-1935).

Figure 11 gives the transversal section of a double track overbridge with three main beams, continued over three spans

Fig. 10. — *C.F.F.* : Bridge over the Rohrbach. — Gothard line, km 66.904; 59.54 m span. — Reinforcement by adding diagonals.

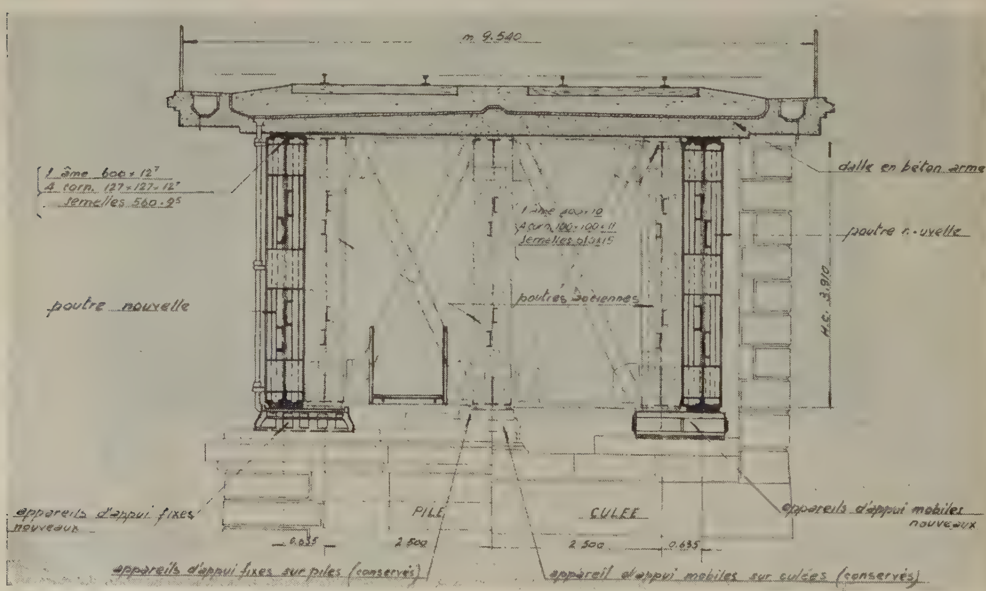


Fig. 11. — *S.N.C.F.* : Bridge over the Lot atC apdenac. — (2 end spans of 41.873 m and 1 central span of 46.666 m). — Reinforcement of the metal deck and addition of reinforced concrete decking.

(41.873, 46.666 and 41.873 m) where the S.N.C.F. has used the methods given under *a.* 3) and *a.* 8) above.

We would point out that the method given in paragraph *a.* 4) (addition of a lower truss) can be used to reinforce cross

Fig. 12. — *F.S.* : Reinforcement of the cross stays and stringers by adding a lower truss.

stays as well, as is shown in figure 12 which shows this being done on the F.S. and figure 3 where a similar device is shown used by the Finnish Railways to reinforce the floor of a 100 m long bridge.

Arrangements under groups *b*), i.e. those intended to reinforce the section of old parts are very varied. The drawings in Plate 8 show some examples of reinforcing the stringers, cross stays, chords of the diagonals, centres and assemblies carried out by the C.F.F.; figure 14 shows the reinforcement of a centre also carried out by the C.F.F. and finally figures 15, 16, 17 and 18 show the reinforcement of chord members carried out by the R.E.N.F.E.

Reinforcements by means of increasing the section of old parts have been carried out by nearly all the Administrations, but the frequency with which they have been done or used varies a lot. In general, the Administrations who have reinforced the main beams by one or other of these methods included in group *a*) have had at the same time to strengthen the floor and for this they have generally used arrangements in group *b*). Many Administrations, mainly colonial railways, have reinforced the main beams by adding plates to the chord members or by reinforcing or replacing the trellis bars. Such work when done by rivetting requires particular care. The A.O.F. Railways mentions that such work should be done on site.

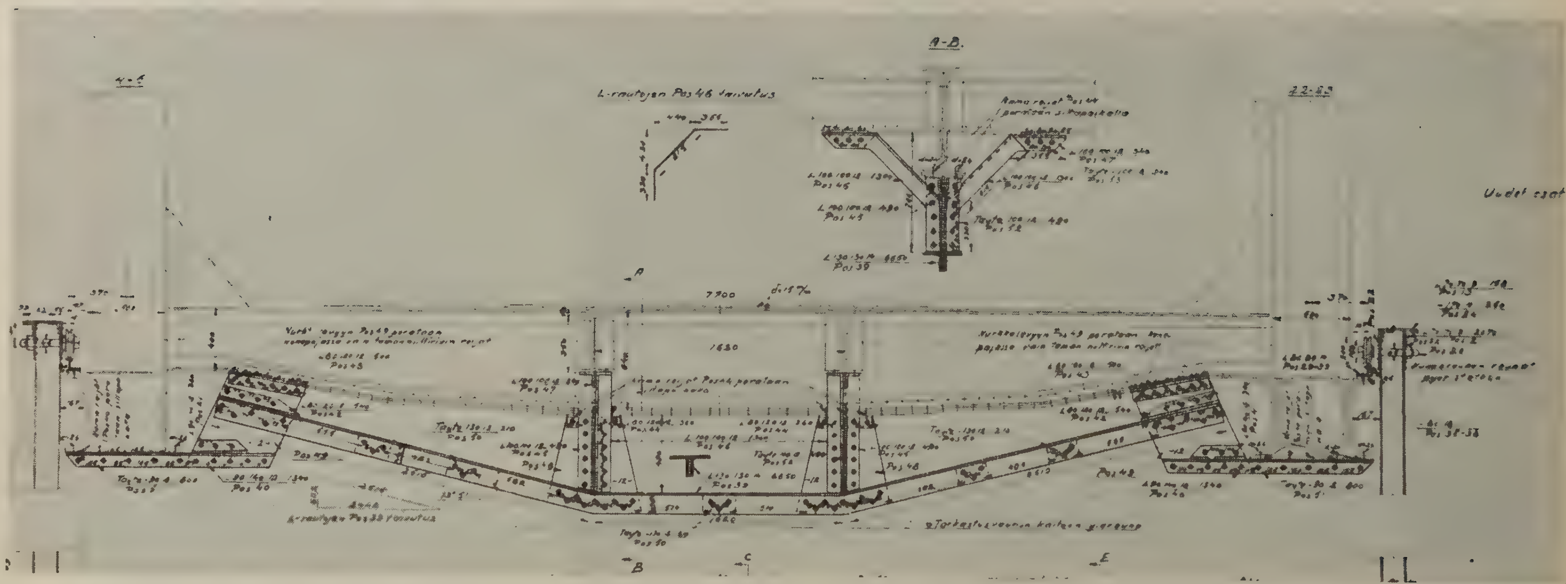


Fig. 13. — *Finnish State Rys.* : Reinforcement of the cross stays by the addition of a lower truss.

The complete overall reinforcement of bridges in Europe has recently been carried out by the S.N.C.F. and the R.E.N.F.E., generally using welding. Most of the other European Administrations, including those which used to strengthen considerably their iron bridges, now only do so to a limited extent.

General reinforcement work is carried out on site, and except in exceptional cases, the permanent load is supported by the old structure whilst the additional parts and increased sections only strengthen the resistance to overloads.

This fact is of no practical importance in the case of the floor chord members and for the wind bracing, where the stresses due to the permanent load are minimum, but on the contrary is extremely important for the chord members of the main beams where the added materials can with difficulty be fully made use of.

Fig. 14. — *C.F.F.* : Bridge over the Broye at Moudon. — Palizieux - Payerne line, km 37.750; 34.20 m span. — Reinforcement of a centre.

Fig. 15. — *R.E.N.F.E.* : Reinforcement of lower flange.

Fig. 16. — *R.E.N.F.E.* : Reinforcement of lower flange.

In cases where as in paragraph *a.* 1) the added support bears the stresses, even of the permanent load, the beams are stressed as required by means of jacks.

In cases like paragraphs *a.* 4), *a.* 5) and *a.* 6), it is possible, by means of special assembly devices, to put a large proportion of the dead weight on the added components, but the results of such arrangements are difficult to estimate.

Fig. 17. — *R.E.N.F.E.* : Reinforcement of upper flange.

2.92) *Do you think it is advantageous in general to strengthen bridges in order to enable them to take heavier loads? Please state what factors you take into account in estimating the advantages to be obtained from strengthening an old bridge which is still in good condition rather than replacing it by a new bridge.*

There was an amazing difference between the replies received. To understand these differences better, it is necessary first of all to ascertain the motives.

Above all, it is necessary to take into account the time at which the bridges to be strengthened were built, and consequently the materials used. In the case of the large European railways, in general, there is no need at the present time to strengthen any bridges of recent construction to allow of heavier loads. The typical trains used for the calculations of these bridges in the last 40 to 50 years generally took into account the probable future increase in the weight of locomotives in addition to the incrases which occurred at the end of the last century.

This explains why the bridges built by the F.S. since 1903 are still able to take the heaviest locomotives without any restrictions; whereas between 1905 and 1915, it was necessary to reinforce several

bridges mostly built during the previous twenty years.

On the large European Administrations, the existing bridges needing reinforcement are in consequence very old bridges, mostly of puddled iron. These Administrations are therefore faced with the question above all : « Is it advisable to strengthen bridges built of these materials ? » As we have seen opinions on this point differ. The situation is very different in overseas countries, who were asked the same question. In practice, it is generally a question of relatively recently built bridges, in mild steel, which have not had to stand up to a great deal of traffic, and consequently are built on very up-to-date lines.

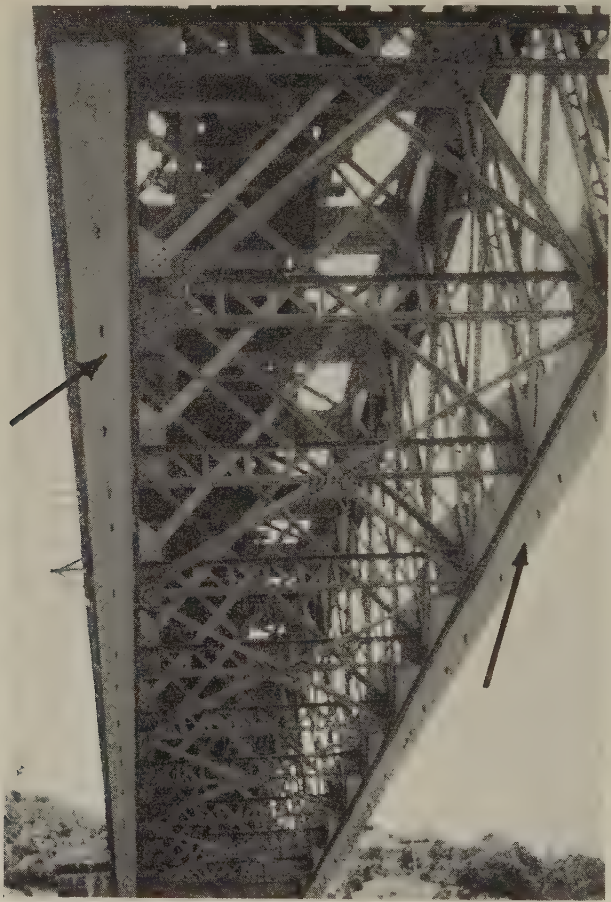


Fig. 18. — *R.E.N.F.E.* : Reinforcement of lower flange.

In the case of bridges which are not more than 20 to 40 years old, like those of the Viet-Nam Railways, or like 5 bridges reinforced in 1951 by the Lower Congo to

Katanga Railways, it is possible to get good results by reinforcing them, and the choice between strengthening or replacing depends entirely upon economic considerations.

Another factor to be remembered in evaluating the replies is the different amount of traffic on the different railways, and consequently the difference in the amount the operating will be upset by the carrying out of the work. In this connection, it should be noted that certain Administrations, amongst the reasons which may make it better to reinforce a bridge than replace it, report that reinforcement can take place without interrupting the traffic.

No Administration affirms in its reply an opinion to the contrary. The S.N.C.F. however state that the choice between reinforcement and replacement must take into account the facility with which the work can be done and the upset to the traffic entailed.

In this connection, the S.N.C.F. in the 1949 report, which we have already quoted, affirmed that reinforcement caused more of a disturbance than replacement.

In fact, the reporter reminds us that, except in exceptional cases, the best method for reducing to the minimum the disturbance to the traffic is to construct the new bridge alongside the old and then open the new bridge by moving both the old and new bridge transversally.

The interruption to the traffic required to carry out this work is generally only between one and two hours, and the only other disturbance is the speed restriction imposed for a few days.

Carrying out of strengthening works on site, on the other hand, may involve much greater disturbance : speed restrictions and interruptions to the traffic at repeated intervals, even if only for short periods.

These disturbances, in particular the speed restrictions, are costly. The F.S. calculate that on a line with heavy traffic, the cost for each day speed restrictions are in force may vary between 0.2 and 0.4 % of the cost of a 40 m span single track bridge.

The importance of a longer period of speed restrictions necessary while reinforcements are being made is therefore the determining factor in the case of bridges on the more important lines.

It should be noted that the F.S. generally do not make use of welding, which would probably make it possible to carry out the work with less disturbance to the traffic.

* * *

The considerations reported above may explain why the overseas railways, who were asked this question are in favour of reinforcement, except in he case of small bridges of 5 to 10 m span for which reinforcement is rejected by nearly every country.

As we have already said, the case of the large European Administrations covered by this report, is very different.

The Administration most in favour of reinforcement is undoubtedly the S.N.C.F. which is carrying out the general reinforcement of both iron and steel bridges, using welding in the case of the latter also. The S.N.C.F. affirm that, in general, the financial and technical preliminary studies in the case of most of the large bridges lead to the conclusion that reinforcement costs less than replacement.

The R.E.N.F.E. thinks that reinforcement is only advantageous when the bridge is made of steel, and if the weight of the materials used for strengthening it do not exceed 20 % of the weight of the old bridge.

The Portuguese Railways agree that the weight of the metal to be added may reach 25 %.

The Czechoslovakian Railways state that reinforcement is advantageous when by using a relatively small amount of steel, it is possible to obtain a striking increase in the load capacity, and on condition that the cost does not exceed 30 % of the cost of a new bridge.

The C.F.F. state that reinforcement is not of interest unless it is of limited extent, and can be carried out under good conditions and when the condition of the bridge makes it reasonable to count upon a fairly long life.

The reply received from the C.F.L. was in principle in favour of reinforcement.

The Finnish Railways merely stated that reinforcing the floors of some old bridges of long span proved advantageous.

The M.A.V. deny the value of any radical strengthening of old bridges but are in favour of strengthening certain isolated parts at moderate cost which will prolong the life of the bridge by a few years.

The N.S. think that in general the condition of old bridges makes it impossible to derive any advantage from reinforcing them.

The S.N.C.B. is also against the strengthening of old bridges, as is the F.S., since these old bridges are usually made of puddled iron. The F.S., however, allow certain small strengthening work to be done provided this only costs very little.

M. CASSÉ in paragraph *c*) of his Report to the Enlarged Meeting of the Permanent Commission of the I.R.C.A. (Lisbon 1949) went into full details of all the motives which can explain these divergent opinions on the subject of the advantage of reinforcing bridges. We give below some brief considerations, referring to this report.

The difference between the extreme opinions, i.e. those of the S.N.C.F. and the F.S. may well be explained by the different opinions these two Administrations hold concerning the strength of the puddled iron of old bridges. However, the C.F.F. as well as the S.N.C.F. deny that the ageing of the iron is confirmed in practice, but in spite of this the C.F.F., contrary to the S.N.C.F., do not think it of value to strengthen old bridges unless they are very small ones.

According to the C.F.F. reinforcement can only be considered when it is :

$$a) \qquad P_r < P_n \frac{r}{n} - r\,(E_r - E_n)$$

in which P_r and P_n represent the total direct and indirect expenditure involved in the reinforcement and the replacement; r and n represent the probable life of the reinforced bridge and the new bridge; and E_r and E_n the annual cost of maintenance. This formula does not take the interest into account.

If the interest is to be taken into account, i representing the rate of interest, theoretically the highest value of P_r can be obtained from the formula :

$$b) \qquad (P_n - P_r)\,(1+i)^r - (E_r - E_n)\,\frac{(1+i)^r - 1}{i} \geq P_n\,\frac{(1+i)^n - (1+i)^r}{(1+i)^n - 1}$$

From this formula, it is apparent that the saving obtained by the reinforcement, increased by the compound interest at the end of the period r, less the greater maintenance costs, which will also be capitalised at the end of the period r, will be the greater as the reduced value of ageing of r years of a hypothetical bridge built at the same time as the reinforcement.

The expression written before, solved in relation to P_r gives :

$$c) \qquad P_r < P_n \frac{k_r}{k_n} - k_r \frac{E_r - E_n}{i}$$

in which

$$k_r = \frac{(1+i)^r - 1}{(1+i)^r} \quad \text{and} \quad k_n = \frac{(1+i)^n - 1}{(1+i)^n}$$

We see that formula *c*) differs slightly from the formula given by M. CASSÉ in his report.

The difference is due to a different evaluation (according to the reporter theoretically more accurate) of the value of the new bridge r years after it was built.

To get an idea of the importance of each factor, we can consult the two tables given below.

In both tables, P_n has been taken as equal to 1 000 and $E_r - E_n = 2$.

In the first table, r has been taken as equal to 25 years and with different rates of interest, the highest values of P given by formula *c*) have been calculated for two values of n (life of the new bridge) i.e. for 67 years and 100 years.

In practice, if the rate of interest is equal to or above 4 %, the presumed life of the new bridge is of little importance. In the second table, taking n = 100 years, the highest values of P given by formula *b*) have been related to different rates of interest, and for values of r (life of the reinforced bridge) increasing progressively from 5 to 50 years.

This second table brings out the importance of the expected life of the reinforced bridge.

From the economic point of view, therefore, the factors which are of the greatest importance as regards the value of reinforcement are: the lowest cost, the expected life of the reinforced bridge, and the cost of money.

Formula *b*) takes no account of variations in costs about which it is difficult to make any prophecies.

TABLE 1.

N°	$i = 0$	$i = 0.001$	$i = 0.00625$	$i = 0.01$	$i = 0.04$	$i = 0.05$	$i = 0.06$	$i = 0.07$	$i = 0.08$	
67 years	325	331	372	406	644	705	758	801	838	$P_n = 1\,000$ $E_r - E_n = 2$
100 years	200	210	264	305	606	681	745	793	833	$r = 25$ years

TABLE 2.

	$i = 0$	$i = 0.001$	$i = 0.00625$	$i = 0.01$	$i = 0.04$	$i = 0.05$	$i = 0.06$	$i = 0.07$	$i = 0.08$	
5 years	40	42	58	67	173	209	245	279	311	$P_n = 1\,000$
10 years	80	85	112	131	315	373	428	478	523	$E_r - E_n = 2$
15 years	120	127	163	192	431	502	565	620	668	$n = 100$ years
20 years	160	168	214	250	527	603	668	721	765	
25 years	200	210	264	305	606	681	744	793	833	
30 years	240	251	312	358	670	743	801	844	878	
40 years	320	334	404	455	768	830	875	907	930	
50 years	400	415	490	543	834	883	917	939	954	

M. CASSÉ in the previously quoted report brings out the constrasting influence which, during the immediate post-war period might have higher cost, on the one hand, and on the other, the difficulty of obtaining materials.

The position from 1949 to the present day has obviously changed but today as formerly the financial position of the Administrations is restricted, and in general does not make it possible for them to modernise their systems completely.

The saving obtained by reinforcing a bridge instead of replacing it by a new bridge will make it possible to carry out some other more useful work.

It would appear therefore, that whenever the quality of the materials and the maintenance conditions of a metal bridge do not exclude the possibility of reinforcing it, the advantages of reinforcing should be carefully gone into and evaluated.

Although such an evaluation must be made with great care both as regards the cost of reinforcing, the carrying out of which may comme up against all sorts of unexpected difficulties, and as regards the life of the reinforced bridge.

3. Bridges and viaducts in masonry and concrete.

The following Administrations did not reply to this part of the questionnaire :

— Lower Congo to Katanga Railway;
— Upper Congo to the Great African Lakes Railway;
— Damas-Hama Railway.

The replies received from 22 Administrations have therefore been taken into consideration.

3.1) *What are the different kinds of damage which occur owing to the age of the bridges and approximately how often? The damage in question may be due to :*

3.11) *defects in the materials;*

3.12) *defects in the design;*

3.13) *poor execution of the work;*

3.14) *atmospheric conditions and ageing;*

3.15) *lack of maintenance;*

3.16) *settling of the ground;*

3.17) *causes other than those mentioned above.*

The Jugoslavian Railways merely stated that they do not keep any statistics of the different kinds of damage and how often it occurs.

The Finnish Railways have not sufficient experience to reply in view of the small number of masonry and concrete bridges on their system and the comparatively recent date of any there are.

The Djibouti to Addis Ababa Railway limited its reply to masonry bridges, as its reinforced concerte bridges are all of very recent construction and so far have not shown any signs of damage.

According to the Portuguese Railways, damage very rarely occurs in the case of masonry bridges. The Cameroons Railways state no systematic damage exists.

This is also the opinion of the O.T.R.A.C.O., which operates the Matadi-Leo Railway. On this line, which was built between 1923 and 1932, only a few cases of damage have occurred due to settling and undermining of the ground.

Sixteen Administrations (including the Djibouti to Addis Ababa Railway) replied that a certain number of cases of damage had occurred, the causes of which were under investigation.

However, any classification of damage occurring on account of the age of the bridge is still more difficult in the case of masonry and concrete bridges than with metal bridges. In fact, it is very difficult to distinguish between damage due to defects in the materials, design, construction, etc. This explains why the same sort of damage may have been classified in a different way by different Administrations.

Deterioration of the concrete because of

the poor quality of the aggregate is included by certain Administrations amongst the damage due to defects in the materials, whilst by other Administrations it is attributed to carrying out the work badly, and in fact, in the case of an old bridge, when insufficient importance was given to the granular structure, this deterioration of the concrete might also be attributed to a defect in the design.

It can be concluded that the main divergencies in the replies received are due, even more than to the different local conditions, to the different points of view from which certain Administrations considered the question.

In general, however, all the Administrations who gave detailed and fully explanatory replies, in one way or another, said how difficult it was to establish any definite classification of the causes of damage and their importance.

3.11) *Defects in materials.*

Most of the Administrations replied that damage had occurred due to defects in the materials, but whereas certain Administrations said that this was exceptional, others on the contrary attributed a great deal of importance to this cause of damage. The Viet-Nam Railways, for example, attributed to defects in the materials 25 % of the damage noted, and the West African Railways stated that most of the damage is due to defects in the materials, above all the poor quality of the sand used.

Below, we list the defects in materials which, according to the replies received, may cause damage :

a) *porous, flawed, or badly fired bricks, which flake and disintegrate when exposed to the weather.* (S.N.C.B., R.E.N.F.E., S.N.C.F., F.S., Czechoslovakian Railways);

b) *poor quality stone* insufficiently resistant to crushing (Djibouti to Addis Ababa Railway, F.S., C.F.L.) flaws in the stone, or more often, stone with insufficient resistance to the weather (S.N.C.F., F.S., C.F.L., C.F.F., Czechoslovakian Railways);

The M.A.V. report that at the end of last century abutments were built in which tuff stone was used for the interior parts of the masonry which soaked up any water that penetrated and swelled up, and as a result these abutments burst.

c) *poor quality cement.*

The S.N.C.F. and the Algerian Railways report that the poor quality of the cement may be one of the causes of damage. The F.S. report that they have come across certain cases of rapid deterioration of the reinforced concrete on bridges built immediately after the end of the war, and this deterioration was partly the result of using poor quality cement. The C.F.F. mention amongst the causes of damage, defective materials, (particularly lime) and the use of aluminious cement in mortar and concrete.

The Czechoslovakian Railways and the Djibouti to Addis Ababa Railway report that poor quality mortar may be cause of damage, but they do not specify whether the defect in the material is due to the cement or sand used.

d) *poor quality of the aggregates.*

This cause of damage has been gone into in detail, in particular by the D.S.B.

The natural deposits of sand and gravel in the country always contain a certain amount of lime, and it is difficult to prevent it being present in the concrete, which results in concrete with crater like holes in it.

During the last few years, however, the D.S.B. have given particular attention to evaluating the importance of the « harmful alcaline reactions ».

The chemical reactions of alcaline matter present in the concrete (due to the

alcaline content of the cement or aggregate, or brought in by the use of sea water, for example) with the silicic acid present in the aggregates, results in the formation of « expanding frost », colloidal material, which may cause the disintegration of the concrete.

This question is being studied in Denmark by a special Commission. The D.S.B. state that they are becoming more and more convinced that these harmful alcaline reactions are often one of the causes, perhaps even the chief cause, for the crumbling which is often noticed in certain concrete bridges, even recently built ones

The F.S. report certain cases of crumbling in reinforced concrete bridges built in a hurry immediately after the war near the sea.

The F.S. attribute this to the use of sand and gravel which was not excavated and washed according to the regulations in force, and consequently, according to the F.S., this is a case of defective carrying out of the work.

In the same way, several Administrations report in their reply to question 3.13 (faulty carrying out of the work) damage due to defects in the granular structure or caused by impurities in the aggregate.

3.12) *Defects in design.*

The Djibouti to Addis Ababa Railway has not noticed any damage attributable to defects in the design, the Viet-Nam Railways attribute 1 % of the cases of damage to such defects, and the N.S. state that small defects may be the cause of serious damage, but do not go into any details.

Twelve Administrations have reported damage caused by defects in the design, amongst them the F.S. and the C.F.F. who gave long lists of such damage :

a) *Reinforced concrete in which the insufficiently protected reinforcement was laid bare:*

This type of damage is mentioned here by the S.N.C.B. and the D.S.B. These Administrations however, and in general most of the other Administrations, attribute this type of damage to defective carrying out of the work;

b) *lack of or inadequate expansion joints in reinforced concrete bridges :* S.N.C.B., Algerian Railways, F.S., C.F.L.;

c) *crumbling of the concrete because of the type of straps used (flat irons) :* S.N.C.B., F.S.;

d) *longitudinal cracks in reinforced concrete bridges due to insufficient transversal reinforcements :* Algerian Railways, F.S.

The C.F.F. have found similar cracks in certain decks with beams embedded in the concrete;

e) *Crumbling of the concrete in certain lightly reinforced concrete arches where the straps were insufficient to overcome the tendency of the bars to take up the position of the chord :* F.S.;

f) *Cross stays arranged at right angles to the ribs in skew bridges of reinforced concrete :*

Because of the fact that where the cross stays are fastened to the ribs, the latter do not give equally, there may result abnormal shear and torsion effects, which may cause cracks (F.S.);

g) *Absence or insufficient drainage arrangements. Arrangements which make it difficult to clean out the outlets of the guttering on masonry bridges :* S.N.C.F., « Chemins de fer Economiques », F.S., C.F.F., Czechoslovakian Railways.

The C.F.F. also report that it is sometimes necessary to provide some method of heating to prevent the drains freezing up;

h) *Absence of any watertight casing or a casing made of material which cracks easily :* S.N.C.B., D.S.B., F.S., C.F.F.

The point is dealt with more fully under 3.31.

i) *Abutment-piers unable to stand up to unilateral thrust :* C.F.F.;

l) *Loose filling up on the arches between the spandrels whence thrust on these latter :* C.F.F.

This thrust is increased wherever the inside walls of the spandrels are inclined and have no skewback, so that consequently the filling in acts as a wedge. Consequently, cracks are sometimes found in flank-walls and wing walls due to the abnormal thrust of the embankment (F.S., Czechoslovakian Railways);

m) *Cracks between the arch and spandrel owing to the rigidity of the latter :* (F.S., C.F.F.) and also because of the different thermal expansion where the masonry of the spandrels differs from that of the arch (F.S.);

n) *Angle chains and quoins of the heads of the arch of different quality than the pillars and arch,* resulting in longitudinal cracks (C.F.F.) and dislocation of the exterior part when this is more rigid (F.S.);

o) *Insufficient layer of ballast :* C.F.F. See also 3.41;

p) *Longitudinal and tranversal hollows on the arches :*

These hollows are not always accessible. It is not possible to see if any cracks have occurred so that the necessary repairs to prevent the water getting in are not done, which may result in the general deterioration of the masonry;

q) *Defective isolation of the expansion joints :*

The M.A.V. state this defect is often the cause of damage, and no satisfactory arrangement has yet been discovered for these joints;

r) *Cracks in the superstructure due to settling of the ground :*

This is dealt with under No. 3.16 but some Administrations attribute the insufficient depth of the foundations for the piers and abutments to defective design (Czechoslovakian Railways), or to the use of statically undetermined structures where the foundation site is poor (F.S.);

s) *Dislocation of the quoins of the head of the arch and the spandrel walls under the action of centrifugal force :* (F.S.), especially at the entry of bridges immediately beyond small radius curves (C.P.).

3.13) *Defective carrying out of the work.*

Amongst the Administrations, who replied to this question, the N.S. merely stated that they have found that damage due to faulty carrying out of the work is very soon noticed, the Algerian Railways report that such defects are extremely rare, whilst the Viet-Nam Railways state that they account for 30 % of all damage and according to the Djibouti to Addis Ababa Railway 50 %.

Other Administrations mention certain damage under this heading which for the most part has already been considered under 3.11 and 3.12.

a) *Reinforced concrete in which the reinforcement is visible on the outside not having been properly dressed and bound in :* S.N.C.B., D.S.B., S.N.C.F., « Chemins de fer Economiques » ,F.S., C.F.L., C.F.F.

b) *Defective granular construction :* D.S.B., S.N.C.F., F.S., C.F.L. *Concrete with pockets of gravel :* S.N.C.B., *porous concrete* (C.F.F.) too much water used in making the concrete (D.S.B., F.S.).

c) *Concreting done under unfavourable weather conditions :* F.S.

d) *Concrete dropped from too great a height, particularly when used in the construction of the piers :* C.F.F.

e) *Making concrete arches without following the proper succession in making the quoins and without a sufficient time lag between making adjoining quoins :* F.S.

f) *Carelessly made connections at the isolating joints :* C.F.L.; defective isolation of expansion joints : M.A.V., or joints where concreting has been interrupted being too clearly marked : S.N.C.B.

g) *Rubble not laid according to its natural quarry bed :* C.F.L., C.F.F. or laid on an edge or point : C.F.F.

h) *Defective connections between the facings* (parements) and angle buttress piers (inadequate headers) : « Chemins de fer Economiques », C.F.F.

i) *Careless drainage arrangements :* C.F.L.

In general from the replies received, it appears that cases of faulty execution of the work are not frequent.

The F.S. report that such cases, which are always rare, nearly always date back to the immediate post-war period and are due to the haste with which the work of reconstruction was done.

3.14) *Atmospheric conditions and ageing.*

Five Administrations (O. T. R. A. C. O , « Chemins de fer Economiques », Cameroons Railways, West African Railways, C.P.) did not answer this question.

The J.D.Z. and the Finnish State Railways were not able to give any precise information.

The C.F.L. had no damage to report under this heading.

On the other hand, the S.N.C.V. and the Tunisian Railways stated these are one of the main causes of damage.

The Viet-Nam Railways merely mentioned their frequency, estimated to be 15 % of the total damage occurring.

The Djibouti to Addis Ababa Railway report crumbling of the stone due to bad weather, and the Algerian Railways slight deterioration of the stone throught atmospheric causes.

Atmospheric conditions are often combined with defects in the materials (3.11), defects in design (3.12), defects in construction (3.13) and defects in maintenance (3.15) (N.S.).

The C.F.F. confirm that atmospheric conditions reveal the various defects more or less rapidly.

a) *In the case of masonry bridges,* atmospheric conditions prejudicial to the proper conservation of the bridges, according to the S.N.C.F., are above all frost, which gets into the stones and bursts them. It also damages bricks (F.S.) by getting into the joints, after the mortar has come away, because of sudden variations in temperature and the different degrees of expansion of the cement.

In this connection, the R.E.N.F.E. state that on certain old bridges, the deterioration of the bricks in the arches and spandrels has made it necessary to strengthen the arches and replace some of the masonry by concrete.

The M.A.V. no longer use bricks to build bridges, as they so frequently suffered damage from frost, usually as a result of defects in isolation (draining water away).

The M.A.V. also blame frost for the loosening of single supports of dressed stone here and there on old bridges, whilst the F.S. considered that such loosening is mainly due to vibrations (and as a result replace them by a continuous supporting bank of reinforced concrete).

A classical type of damage, also due to atmospheric causes — which has already been taken into consideration as due to defective design (see 3.12) and wich could also be attributed to defective construction — is separation at the keystones (S.N.C.B.) caused by the thrust of water

saturated soil which increases in times of frost.

The water gets into the cracks and aggravates this position.

The F.S. consider that the deterioration of old masonry due to water getting in depends above all on the inadequacy or poor condition of the casing and the drainage.

The Czechoslovakian Railways state that the deterioration through exposure and the ageing of the materials is seen above all in very damp bridges or where lamellose stone has been used with the natural bed parallel to the facing. This results in serious flaking.

Deterioration due to the above causes naturally occurs more rapidly in the case of bridges made of rough stone filled in with inferior mortar.

b) In reinforced concrete bridges, atmospheric conditions, especially alternate freezing and unfreezing, as well as alternate dryness and humidity, may lead to serious damage, but the prime cause of such damage is in general poor execution of the work (see No. 3.13 *b*) or the use of poor quality materials (see No. 3.11).

In bridges close to the sea, serious damage may result from the salt laden atmosphere which also penetrates into the ordinary capillary cracks in the concrete and deposits salts which lead to swelling and facilitate the corrosion of the steel and the deterioration of the whole structure.

3.15) *Lack of maintenance.*

Only 10 Administrations answered this question.

The D.S.B., R.E.N.F.E. and the C.F.L. have not had any cases of damage due to lack of maintenance. According to the D.S.B., this is due to the fact that the bridges are regularly inspected and maintenance work is then carried out as quickly as operating and economic conditions allow.

Furthermore, for years they have been trying to improve maintenance methods.

The Djibouti to Addis Ababa Railway states that such damage is rare. According to the Viet-Nam Railways such damage accounts for 8 % of the total.

On the S.N.C.F., the bridges are generally well maintained; however the maintenance could not be carried out regularly during the war, and damage increased, which involved increased maintenance work.

According to the N.S., defects due to lack of maintenance are small.

The C.F.F. state that by delaying or neglecting maintenance work, the defects are aggravated and the damage caused increased.

The M.A.V. observe that the deterioration which increases, due to lack of repairs at the proper time, in frost affected masonry is attributable to insufficient maintenance.

But it is hard to discover such damage, which is hidden, and in the case of slight deterioration of the isolation, inspection whilst the bridge is in service, which is always extremely difficult, is not always practicable.

The F.S. report that often operating needs prevent or delay repairs to make good the casing. The maintenance of bridges is insufficient in certain cases because of financial difficulties.

The Czechoslovakian Railways report damage due to the blocking up of the drainage and the resultant poor evacuation of the rainwater; watertight casings in poor condition have not been repaired and this causes the deterioration of the facings through the action of water and vegetation rooting in the joints.

The Algerian Railways report that the effects of lack of maintenance are greater in the case of concrete bridges, and quote as an example the case of rusting of the reinforcement on a foot bridge near the sea (see 3.14 *b*).

3.16) *Settling of the ground.*

Seven Administrations did not answer this question (S.N.C.V., O.T.R.A.C.O.,

Finnish State Railways, Cameroons Railways, French West African Railways, C.P. and J.D.Z.).

The C.F.L. have no damage due to this cause to report, and the Algerian Railways only report a few accidents in the case of arched bridges.

The D.S.B. agree that settling of the ground does occur, but this has not led to any serious consequences.

According to the M.A.V. and the N.S., damage has only occurred in a few isolated cases.

On the « Chemins de fer Economiques » also such damage is exceptional; on the other hand, the Tunisian Railways state that this is amongst the most frequent causes of damage; the French West African Railways consider that it accounts for 25 % of all damage and the Viet-Nam Railways : 20 %.

Settling of the ground can be due to :

a) subsidences due to its compressibility, which usually occurs as a result of the compression it undergoes without any harmful effects, but which may also lead to damage, sometimes serious, when the bridge is built on ground of varying nature, so that there is a different degree of subsidence from one point to another.

If there are variations in the compressibility in the direction of the track, they will result in cracks in the arches following the generants, whereas when the degree of compression varies transversally, there may be cracks in the abutments (M.A.V.) and consequently cracks in the arches, following the directors (F.S.) and in the decking, in a longitudinal direction (C.F.F.).

Unequal subsidences of the ground in one direction and another may lead to complex cracks due to torsion in both the arches and the decking.

The loosening of the arch spandrels and the facing stones reported by the C.F.F. may be attributed to the same cause.

Cracks caused by irregular subsidences of the ground have also been reported by the S.N.C.B., but only in the case of small bridges with arches.

Sometimes displacement of the foundations may be caused, in addition to the actual weight of the bridge, by indirect subsidences of the ground as a result of loads during the building of the bridge, for example when making a large embankment (S.N.C.B., F.S.).

b) *Plastic deformation of the ground.*

The F.S. report a few cases of foundations built on clayey or peaty ground which have continued to subside, although consolidated by driving stakes, but on a gradually decreasing scale, until the final degree of settlement was reached.

c) *Deterioration in the ground under the foundations.*

The F.S. have noted in certain cases the deterioration of marly soil which was protected from the water whilst the foundations were being built, as a result of which water has been able to seep into the masonry embedded in the ground and into the foundations.

d) *landslides,* which may lead to very considerable damage of all kinds (F.S.);

e) *the laying bare of the foundation* due to flooding of the water courses (R.E.N.F.E., F.S.);

f) *undermining of the foundations* due to underground springs;

g) *subsidences due to mining* in certain coal bearing districts (S.N.C.B., S.N.C.F., Czechoslovakian Railways).

3.17) *Causes other than those mentioned above.*

Most of the Administrations did not answer this question. Other Administrations stated that they had not noticed any damage due to any causes other than those already considered.

The Czechoslovakian Railways mentioned

in this connection the action of water seeping in, which we have already considered in the previous question.

The S.N.C.B., S.N.C.F., F.S. and M.A.V. mention the results of smoke which is harmful to concrete, bricks and steel.

The deterioration it causes in the case of concrete may lead to the ruin of the bridge, as the reinforcements are laid bare and cannot stand up to the corrosion due to the sulphur anydride of the combustion gases for any length of time (S.N.C.B.).

The F.S. state that if the ballast is not sufficiently thick, shocks as the trains pass often cause damage to the tops of the arches, especially below the rail joints.

The cracks due to these shocks run in all directions.

In view of the fact that such shocks were foreseeable, such damage can be blamed on defects in the design.

3.2) *What methods do you use when examining masonry and concrete bridges, including possibly non-destructive processes?*

The S.N.C.V., the « Chemins de fer Economiques » and the Tunisian Railways Railways did not answer this question.

The Cameroons Railways, the French West African Railways and the C.P. merely replied that they carry out periodic inspections of bridges (see No. 4.9).

Other Administrations mentioned special methods, but did not consider the question from a general point of view.

The Finnish State Railways test the strength of concrete with a test hammer.

The M.A.V. in doubtful cases make tests on cubes taken from the bridge.

The Jugoslavian Railways carry out tests on masonry and concrete bridges by means of electric extensometers.

The N.S. replied that first of all the bridge is inspected visually and, in the case of concrete, if necessary it is then examined by means of the Schmidt test chamber.

The N.S. also report that when on examination doubt is felt about the safety of the arches, measurements have been made in some cases on a wide scale.

In one isolated case the N.S. carried out a complete examination of all possible factors of damage on a reinforced concrete viaduct.

They did not state however how this was done. The N.S. recently spent 60 000 D. Fl. for research work on a 1 500 m long viaduct.

Here again, however, the N.S. did not give any details concerning the researches carried out.

Two Administrations in their replies mentioned the following method which is normally used to examine masonry and concrete bridges:

a) *Careful visual examination* (sometimes from scaffolding) if necessary by telescope or magnifying glass.

b) *Checking the breaking of test pieces* or the relative movements of gauge points.

c) *Levelling.*

When the stability of a bridge is in doubt, careful periodic checks must be made of the levels and certain dimensions of the bridge in order to follow the evolution of the deterioration (S.N.C.B.).

The S.N.C.B., the Algerian Railways and the O.T.R.A.C.O. do not mention any other methods than those listed under *a*), *b*) and *c*).

The D.S.B., S.N.C.F., Djibouti to Addis Ababa, Viet-Nam, F.S., C.F.L., R.E.N.F.E., C.F.F. and Czechoslovakian Railways carry out the above examinations and in addition have sometimes used one of the following methods when this appeared of use.

d) *Tests of the load:*

The Viet-Nam Railways and C.F.F. merely mentioned that when circumstances made it necessary, they carried out load tests, but they did not give any details.

If the age of the bridge or the seriousness of the cracks noticed justify it, the S.N.C.F. make measurements by means of the following methods :

— measurements of the size of the cracks under loads by means of a vibrograph (comparative recorder on a disc of waxed paper). Such measurements are made perpendicularly and tangentially to the edges of the crack;
— measurement of the general vibratory condition of the bridge under load by means of a sismograph which shows the value of the amplitude and frequency of the vertical, lateral and longitudinal movements, as well as the value of the acceleration of these movements at various points on the bridge;
— the value of the static versines of these bridges being of little significance in general, it is measurements of the rotation or cant that are usually made by means of Bosramier type spirit levels by which 1/40 000 radian can be evaluated.

The F.S. have made periodic measurements of subsidences, rotations and deflections under load, especially in the case of bridges whose foundations are on ground liable to subsidence (see 3.16).

The R.E.N.F.E. has also carried out test loads with electric extensometers and clinometers.

e) *Spot tests by mechanical methods.*

The Djibouti to Addis Ababa Railway and the R.E.N.F.E. merely state that they make such tests, but do not give any details.

e. 1. — *Superficial spot tests.*

The D.S.B., Viet-Nam Railways, F.S. and C.F.L. report that they make spot tests of masonry or concrete by percussion.

The Czechoslovakian Railways use a Waitzman type test hammer.

e. 2. — *Taking samples from inside the masonry or concrete.*

The following Administrations state that they use this method when circumstances make it necessary : the D.S.B., Viet-Nam Railways, M.A.V., F.S., C.F.L., and Czechoslovakian Railways.

The F.S. also state that the samples are generally removed by rotary drilling.

f) *Non-destructive methods of examination* (other than the above).

The S.N.C.F. report that in the case of reinforced concrete and prestressed concrete, checking the position of the irons in the concrete by a magnetic method (pachometer) makes it possible to ascertain if necessary if there is any relation between the position of the irons and that of the cracks.

The S.N.C.F. do not state, however, if this method is currently employed, or has merely been tested.

The D.S.B. and the Czechoslovakian Railways have tried the method using ultrasonic pulsations.

The F.S. have carried out tests on reinforced concerte by Röngten rays and with sclerometers, but the results obtained were limited to the superficial parts.

The Czechoslovakian Railways also mention amongst the non-destructive methods tested, the resonance method, the dynamic method, and the method of direct measurement of the speed of the impulses.

According to the Czechoslovakian Railways, this latter method makes it possible to analyse arches up to 1 m thick.

Perhaps we would also include amongst the methods under consideration here the use of a sismograph when loads are passing over the bridge, which the S.N.C.F. mentioned, and which has been included amongst load tests.

3.31) *On masonry and concrete bridges, including those with concrete encased girders, what materials are used for the casing? What results have been obtained?*

22 Administrations replied to this question.

The types of casing most often used are asphalt coverings, cement coverings and multi-layer casings based on bitumastic products.

I) *Cement mortar casing.* — This is the usual type on the R.E.N.F.E., « Chemins de fer Economiques », Cameroons Railways, Djibouti to Addis Ababa Railway and C.P.

The S.N.C.F. and Algerian Railways now prescribe a type of casing with incorporated cement, i.e. a layer put in position when the concrete it covers was made. In certain cases, this may be reduced to a simple smoothing coat.

Where there is no fear of its cracking, it is now preferred in France to the asphalt casing which formerly was the most widely used.

According to the S.N.C.F. the watertightness of bridges depends to a great extent on the rapidity with which the water can get away. Consequently they stipulate a minimum slope of 3 % under the ballast and 0.5 % in the open.

The S.N.C.F. also think that the effectiveness of the casing is more a function of its proper execution than of its composition. They use a strong cement layer (500 kg/m^3), which is nearly equal to the casing mentioned by the R.E.N.F.E. (400 to 600 kg/m^3) and the S.N.C.B. (500 kg/m^3), which has however given up using this type of casing except on aqueducts.

In fact the S.N.C.B. and F.S. only report the use of cement casings on old masonry arches. The F.S. state that the old casings of this type nearly always are cracked, as a cement casing is not elastic.

The cement casings of the « Chemins de fer Economiques » are not all sound; but the R.E.N.F.E. and the Djibouti to Addis Ababa Railway state that this type gives good results; the S.N.C.F. and the C.P. also state they find it satisfactory.

II) *Asphalt casing.* — This is the current type on the bridges of the following Administrations : S. N. C. B., S. N. C. V., O.T.R.A.C.O., D.S.B., Finnish State Railways, French West African Railways, Viet-Nam Railways, F.S., N.S. and Tunisian Railways.

In general, this casing consists of two layers with joints at right angles of run asphalt, with a base of natural pure asphalt putty, bitumen and sand (100, 10 and 50 kg respectively, according to the quantities prescribed by the F.S.).

The D.S.B. insert between these two layers, which they strengthen with asbestos filaments, another layer of impregnated jute, forming in this way the « thick isolation » which must be included in multi-layer casings for very damp bridges and surfaces, whilst the « thin isolation » in the case of dry sites consists of 2 or 3 coats of a fairly liquid asphaltic-bitumastic solution.

The Finnish State Railways prescribe a coat of a bitumastic solution applied cold and a coat of bitumen applied hot.

The O.T.R.A.C.O. use sand, cement and « Flintkote » bitumastic materials in the proportions recommended by the maker.

The N.S. in isolated cases have made the casing by impregnating a 5 cm thick layer of gravel with Trinidad asphalt.

Four Administrations report on the results obtained : The Viet-Nam Railways state that the results are excellent.

The S.N.C.B. and the F.S. consider that it is necessary to protect this asphalt casing by a coat of cement mortar. The S.N.C.B. report that they demolished a bridge built 25 years ago on which the cast asphalt casing was still in perfect condition.

The Tunisian Railways who cover the asphalt with a further casing of hydraulic lime mortar, have noticed a certain amount of sweating on certain bridges with beams encased in the concrete.

PLATE 10. — **Résumé of the replie**

CE				
Administrations	*Type of casing* *3.31*	*Mix* *3.31*	*Thickness in cm* *3.32*	*Protec* *3.42*
S.N.C.B. (Belgium) . .	coat of cement	550 kg ordinary cement 300 l fine sand 700 l gravelly sand	2 cm	none
R.E.N.F.E. (Spain) . .	coat of strong cement mortar	400 to 600 kg cement to one cubic metre of sand	3 ÷ 5	not cons necessa
S.N.C.F. (France) . . .	layer of cement mortar incorporated, i.e. laid when the concrete is made	500 kg cement per m³ of sand	2 ÷ 3	—
Chemins de fer Économiques (France)	coat of cement mortar	standard mix of cement and river sand	3 ÷ 5	none
Algerian Railways. . . .	coat of cement mortar included when making the concrete	rich mix	3	none
Cameroons Railways . .	coat of cement mortar	—	—	none
Djibouti to Addis Ababa Railway	two coats of cement mortar	Rich mix	3 ÷ 4	none
C.P. (Portugal)	coat of cement mortar	cement and sand; no particular regulations	—	none

…ations to questions 3.31, 3.32, 3.34 and 3.42.

…AR CASINGS

Use	*Taken up over the spandrels* 3.32	*Average life (years)* 3.34	*Reports* 3.31	*Notes*
…d masonry bridges	—	very variable	this type of casing not being elastic, cracks occur very soon	this method has been given up (except in the case of aqueducts)
…urrently used	the casing is not taken over the spandrels	15 ÷ 20 years	good	—
…tly used where there …s fear of cracks	taken up 15 ÷ 25 cm	very variable 20 ÷ 80 years (see note)	satisfactory	the life depends on the care taken in making it, the number and siting of the drain outlets, the nature of the filling-in between the spandrels and the fatigue of the arches and decking
…generally used	complete	Most of the casings are 60 ÷ 80 years old	however they are not all sound	—
ditto	made continuous with the horizontal parts	no exact information available	satisfactory	—
ditto	—	—	—	—
ditto	only over elbow joints. No casing on spandrels	not known	good	—
—	—	so far it has not been necessary to replace them	satisfactory	—

CASINGS					
Administrations	*Type of casing* 3.31	*Composition* 3.31	*Horizontally inclined surfaces*		*Protection* 3.42
			Arrangement adopted 3.32	*Total thickness (weight)*	
S.N.C.B. (Belgium) . . .	2 layers of natural asphalt	pure natural asphalt base	On slopes < 10 % the casing is made independent of the shuttering by the insertion of bituminised felt weighing 900 g/m²	≥ 20 mm	by a layer of concrete 4 ÷ thick, or in ce cases by prefa ated slabs.
			on slopes ≥ 10 % the casing is stuck to the bridge by impregnation with bitumatic paint	(for 20 mm the weight is 45 kg/m²)	
S.N.C.V. (Belgian National Light Railways) . . .	in asphalt	—	5 ply	—	there is
O.T.R.A.C.O. . .	bitumastic materials (Flintkote)	sand, cement and « Flintkote »	the concrete is first made waterproof by « Impercim »	3 cm	by gravel 5/20
D.S.B. (Denmark) . .	thin insulation (2 or 3 coats of an asphalt-bitumastic solution)	liquid asphalt-bitumastic solution	—	—	betw. the casing the filling-in, th a drained laye pebbles 20 cm
Finnish State Railways	2 coats of bitumen:	one applied cold, the other hot	—	—	there is non
S.N.C.F. (France)	2 layers of cast asphalt	100 kg asphalt putty and 8 kg refined bitumen	in 2 layers each 10 mm thick, with joints at right angles	20 mm	top casing of crete
French West african Rys	in asphalt	—	—	3 cm	none
Viet-Nam Railways	2 layers of asphalt	the 1st of putty and 7% bitumen, the 2d of asphalt and 7% bitumen	—	15 mm	top casing in concrete, 4 cm
F.S. (Italy) . . .	2 layers of cast asphalt	10 kg natural bitumen 100 kg natural asphalt 50 kg sand	in two layers, each 10 mm thick, with right angled joints	20 mm	Top casing of c mortar (400 k
N.S. (Netherlands) .	gravel impregnated with pure Trinidad asphalt	—	—	—	there is non
Tunisian Railways	in cast asphalt	—	—	—	top casing of draulic lime m

ations to questions 3.31, 3.32, 3.34 and 3.42.

HALT				
Use	*Reports* 3.32 *Arrangements adopted*	*Thickness (weight)*	*Average life* 3.34	*Results and notes* 3.31
type is that ntly used for s, tubular s, under- d passages, new bridges	the adhesion is improved by horizontal slots or grooves 2.5 cm wide and 2 cm deep at intervals of about 30 cm on the bridge. This is lined out with a steel trellis embedded in a layer of asphalt, on which the 2 layers of the casing are then laid however when it is taken up less than 60 cm, a coat of bitumastic paint is sufficient	13 ÷ 15 mm (for 15 mm, the weight is 33 kg/m^2)	very variable, but on a 25 year old bridge recently demolished the cast asphalt casing was still in perfect order	
ntly used	—	—	20 years	—
idem	—	2 cm	it is not possible to remake the casing	—
surfaces res- against dry nd	—	—	20-30 years	—
—	—	—	—	it was not stated where this type of casing is used
n cracks are d	only a height of 15 ÷ 20 cm is covered	16 mm	—	this type is now only applied in particular cases, because the type with incorporated cement is prefered
the bridges encased gir-	the sides of the hollow are encased	—	should be as long as that of the bridge	—
—	—	—	—	—
ently used	the edges are covered with a 5 ÷ 8 mm thick layer, the top edge of which is notched into the masonry (notches : 3 × 3 cm)	5 ÷ 8 mm	30 years (15÷20 if there is no top casing)	good results
ome cases	—	—	50 years	—
—	—	—	—	a certain amount of sweating has been noticed on some bridges with concrete encased beams

PLATE 12. — **Résumé of the replie**

MULTI-				
Administrations	*Type of casing* 3.31	*Composition* 3.31	*Thickness (Weight g/m²)* 3.32	*Protectio* 3.42
S.N.C.B. (Belgium)	R 500 roofing felt base (bituminised felt with treated surface) with a copper sheet	*(a)* application of bitumastic adhesive paint; *(b)* coat of petroleum bitumen *(c)* layer of R 500 roofing felt *(d)* 1st layer of fibrous adhesive mass *(e)* sheet of goffered annealed red copper *(f)* 2nd layer of fibrous adhesive mass *(g)* 2nd layer of R 500 roofing felt *(h)* 3rd layer of finishing petroleum bitumen	(200 ÷ 400 g/m²) (1 500 g/m²) (2 500 g/m²) 20/100 mm (2 500 g/m²)	a coat of c mortar over ho al surfaces (≤ 10 %)
D.S.B. (Denmark)	thick isolation	2 layers of a thick solution with asbestos filaments with a layer of impregnated jute between them	—	by a coat of c mortar
Finnish State Railways	bituminised sheets	—	—	top casing of c mortar lightl inforced
S.N.C.F. (France)	with a tar paper base	2 layers of tar paper or paper known as « entre 2 sans fil » (2 sheets stuck together with tar) 10 cm overlap at joints	—	top casing in crete (mix 50 m³)
Algerian Railways.	with a bitumastic product as base	—	—	top casing in thick concrete
F.S. (Italy) . . .	with bituminised cardboard and glass asphalt base	3 layers { tar paper, glass-asphalt, tar paper } alternated with 4 coats of pure bitumen 1 mm thick	(1 200 g/m²) (2 500 g/m²) (1 200 g/m²)	top casing in crete 3 cm
		(a) preparation of the surface with a bitumastic paint *(b)* adhesive coat with hot bitumastic putty base *(c)* layer of glass-asphalt with 10 cm overlap *(d)* adhesive layer as under *(b)* *(e)* layer of bituminised felt *(f)* application of adhesive putty as under *(b)*	(1 200 g/m²) (3 000 g/m²) (1 200 g/m²) (1 200 g/m²) (1 200 g/m²)	top casing in crete with 400 cement, 3 cm

...rations to questions 3.31, 3.32, 3.34 and 3.42.

...s				
...Use	Reports 3.32	Average life 3.34	Results 3.31	Notes
...idges and ...ced con-...decking	—	this method has not been in use sufficiently long for its useful life to be known	very satisfactory	it is necessary to supervise the carrying out of the work very carefully, and only have it done by specialist firms
...e decking, ...here water ...nt or where ...very damp	—	20 ÷ 30 years	—	—
...ncrete and ...ry bridges	—	—	—	the reinforcement of the top casing is limited to parts subjected to the effects of shocks
—	—	—	—	the type with the cement incorporated is now preferred
—	—	—	—	This type is no longer used. The incorporated cement casing is now preferred
...ver absolute ...sting water-...ess is neces-	—	Expected to last much longer than an asphalt casing	good so far	—

PLATE 12. — **Résumé of the replie**

MULTI-				
Administrations	*Type of casing* *3.31*	*Composition* *3.31*	*Thickness (Weight g/m^2)* *3.32*	*Protectio* *3.42*
M.A.V. (Hungary)	with jute or bituminised cardboard base	2 layers of bituminised jute and coats of adhesive	8 ÷ 10 mm	yes
		2 ÷ 3 layers of bituminised cardboard and coats of adhesive	10 mm	
N.S. (Netherlands)	with waterproofing sheets	asphalted jute with an adhesive coat or Plastenel and Oppenel	5 ÷ 6 mm	top casing in thick concrete
C.F.F. (Switzerland) . .	with a jute bituminised base	2 layers of jute bituminised alternating with 3 layers adhesive bituminised mass laid on hot	10 mm	light reinforce crete top casing thick with light
Czeckoslovakian Ministry of Transport	impregnated felt and asphalt	3 layers of impregnated asphalt with 2 intermediary layers of felt. The standard covering material is of petroleum pitch base	10 mm	top casing in m concrete 3 cm slightly reinf with trellis
J.D.Z. Jugoslavia	asphalt bituminised paper and jute	—	—	there is none, be no top casin considered nec

...rations to questions 3.31, 3.32, 3.34 and 3.42 *(continued)*.

...GS				
...se	*Reports* 3.32	*Average life* 3.34	*Results* 3.31	*Notes*
...most horizontal surfaces / ...her surfaces ...when water ...sent	to isolate vertical surfaces if water is not always present, it is sufficient to paint over with bitumen (1 coat of cold bitumen emulsion and over it another coat of hot)	15 ÷ 20 years	bitumen is not completely satisfactory, its melting point being too high	—
...ntly used	—	—	—	for tightening of the joints, use is made at present of rubber tape
—	the casing is brought up as far as the plinth of the parapet if this is made of dressed stone or prefabricated concrete blocks. Otherwise, the end of the casing is notched in near the top edge of the spandrel where the reinforcing trellis of the top casing is folded back into the concrete	—	satisfactory	—
—	—	—	pitch, not soluble in water, is not chemically unaffected as the presence of naphthalic acids decays the carbides	—

It appears that there were not a sufficient number of replies to judge whether the length of the effective protection given by asphalt casings, an elastic material but liable to dry out, depends on the type of protection.

III) *Multi-layer casings* having a bitumastic base are used, especially on reinforced concrete bridges, by 7 Administrations, who state that this is the current practice, and by 2 Administrations (S.N.C.F. and F.S.) who use this method where absolute and lasting watertightness is essential.

— The S.N.C.B. mentions a type of casing made of a « R 500 roofing felt » (bitumised felt, impregnated and coated) with a sheet of copper. This type of casing is completely satisfactory. However, it is necessary to keep a very careful check on the way the work is done, and only have it done by specialist firms.

— The D.S.B. make use of the thick isolation described under point II.

— The M.A.V. use two layers of jute in the case of bitumastic casings on nearly horizontal surfaces and 2 to 5 coats of tar paper to isolate surfaces in any position and below water level. The M.A.V. state that the results are not entirely satisfactory, as the melting point of bitumen is too high and it is rather difficult to use.

The Finnish State Railways, the N.S. and the C.F.F. use bitumised fabrics.

— The Czechoslovakian Railways insert two layers of felt between three coats of a petroleum pitch (insoluble in water, but not unalterable, as the presence of naphthenic acids decomposes the carbides);

— The J.D.Z. use bitumen, bitumised paper and jute to make asphalt casings.

IV) *Various casings.* — The D.S.B. sometimes use copper plates covered with steel sheets, and the C.F.L. casings of plastic materials, which so far have given good results.

3.32) *Please give details about the thickness, siting and arrangements adopted for the casing, in particular as regards their extension over the spandrels* (see plates Nos. 10, 11 and 12).

The Finnish, Cameroons and Tunisian Railways did not answer this question; the S.N.C.V., French West African Railways and J.D.Z. merely gave the thickness of the casings.

A) *Thickness and siting of the casings.*

I) *Cement casings.* — The thickness in nearly every case is 3 cm. The R.E.N.F.E. stipulate thicknesses of 3 to 5 cm, and the Djibouti to Addis Ababa Railway 3 to 4 cm.

The S.N.C.F. and the Algerian Railways stipulate that the cement mortar must be put in place when the concrete of the decking of the bridge is made.

II) *Asphalt casing.* — Casings on nearly horizontal surfaces, according to the F.S., the S.N.C.F., and the S.N.C.B. must consist of two 10 mm thick layers, with joints at right angles. The total thickness is therefore 20 mm; the slopes can vary by 13 % on arches to 1 % on the decking.

The S.N.C.B. on slopes $<$ 10 % make the casing independent of the shape by inserting 900 g/m² bitumised felt.

The Viet-Nam Railways stipulate an overall thickness of 15 mm for the casing; the French West African Railways, 30 mm.

The O.T.R.A.C.O. uses bitumastic materials (Flintkote) to which sand and cement have been added in the proportions laid down by the manufacturer of Flintkote. The total thickness for the 3 coats is 30 mm. This casing is applied after the surface of the concrete has been made watertight by using a chemical product called Impercim.

III) *Multi-layer casings.*

The composition, number of layers, thickness and weight of such casings are extremely variable according to the type

adopted by the different Administrations. In this connection, please refer to the data collected in Plate 12.

IV) *Various casings.*

a) The casing made of strips of plastic material adopted by the C.F.L. is 1.5 to 2.5 mm thick, the edges of the strips overlapping by 5 cm.

b) Particular arrangements adopted as regards their extension over the spandrels.

The R.E.N.F.E. do not extend the casing (in cement) over the spandrels and the Djibouti to Addis Ababa Railway merely uses fillets.

The S.N.C.F. raises the casings on vertical walls in such a way as to assure a 15 to 25 cm lap which they consider sufficient to prevent the water getting back up the spandrels.

On the bridges of the S.N.C.B., Algerian Railways, F.S. and C.F.L. the laps are taken up the walls of the spandrels.

The Viet-Nam Railways raise their asphalt casings by a coat of strong cement (500 to 600 kg/m^3).

Details about the characteristics of the overlaps are given in Plates 10, 11 and 12.

C) Arrangements adopted for the casings at the bridge joints.

Very few Administrations gave any details about this.

The Czechoslovakian Railways cover the joints with a strip of galvanised sheet or copper.

The M.A.V. cover the joints by lead or copper plates, 2 to 3 mm thick, which overlap the joints by 15 cm and are inserted between the insulating layers of jute or tar paper.

To support greater movements, the metal plate is curved above the joint.

The F.S. generally cover joints by protective plates of reinforced concrete in the form of a C, placed above the edges of the two parts, so that they are slightly in relief.

Sometimes the joint cover consists of a T section, which rests on the edges of the bridge strengthened by two angles.

The casing covers the whole bridge without break (see Plate 13).

The C.F.F. cover the joints by copper sheets protected by a half concrete pipe (see Plate 13).

The N.S. at the present use exclusively rubber strips to make the joints tight, as copper joint plates of different shapes all let the water get in.

3.33) *From your experience do you consider that the quality of the materials used for filling in the casing contributes to an important extent to the proper conservation of the casing itself?*

The S.N.C.V., the Finnish State Railways, the Algerian Railways and the Tunisian Railways did not answer this mention.

The Cameroons Railways, the French West African Railways, the Djibouti to Addis Ababa Railway lacked comparative data or had no opinions on this subject.

According to the M.A.V. such experience is not possible.

The O.T.R.A.C.O. replied that nothing particular had been noted, but that the casing is always protected by gravel.

The C.P. replied that they observe the current regulations and the N.S. consider that this was a question of no importance which did not need any consideration.

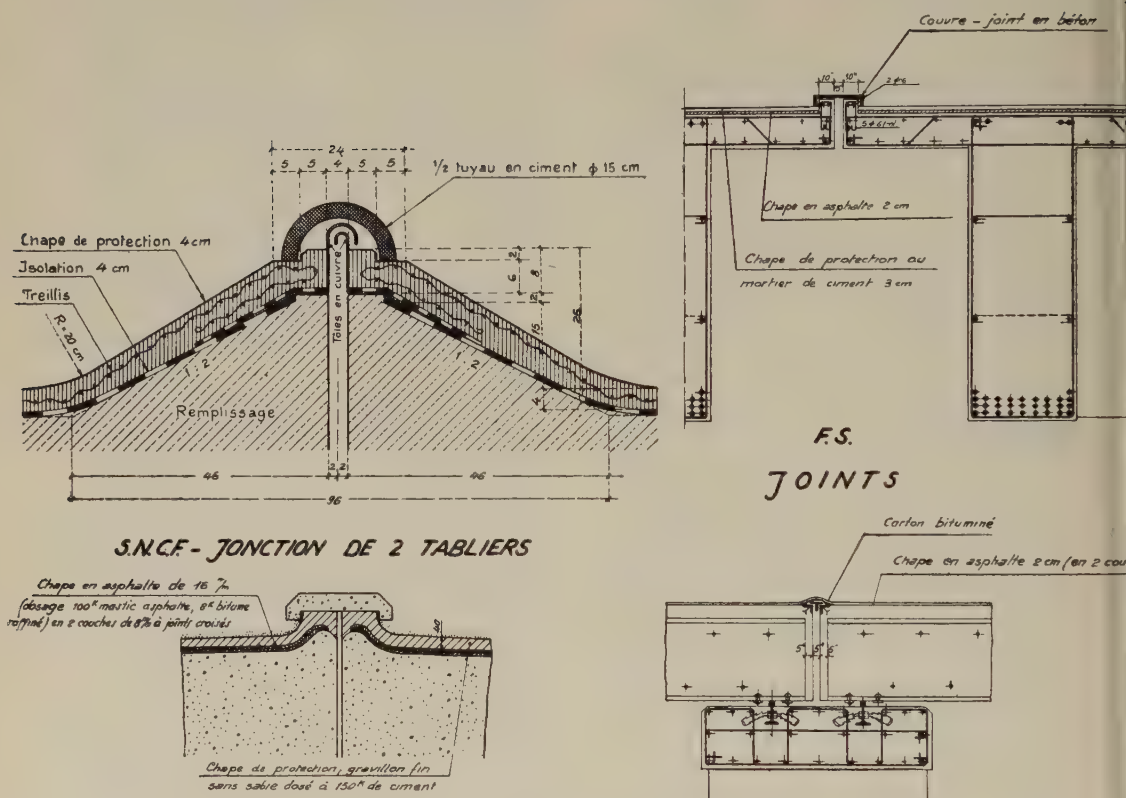
The R.E.N.F.E. and the J.D.Z. merely answered « yes », and the C.F.F. merely stated that they forbid the use of sand on the casings, so that the water can drain off as quickly as possible.

According to the S.N.C.B., the D.S.B., the S.N.C.F., the « Chemins de fer Economiques », the Viet-Nam Railways, the F.S., the C.F.L., and the Czechoslovakian Railways, the quality of the filling-in materials can have an important bearing upon the proper conservation of the casing. which depends upon the fact that the fil-

PLATE 13. — *CASING JOINTS.*

C.F.F. : LONGITUDINAL JOINT.

On double track masonry bridges carried out in two stages (also used with concrete deck slabs).



Explanation of French wording :

1/2 tuyau en ciment diam. 15 cm = 1/2 cement pipe diam 15 cm. — Chape de protection = protective casing. — Treillis = trellis. — Remplissage = filling-in. — Tôles en cuivre = copper sheets. — Couvre-joint en béton = concrete joint plate. — Chape en asphalte = asphalt casing. — Chape de protection au mortier de ciment = cement mortar protective casing. — Carton bitumé = bituminised cardboard. — Chape en asphalte (2 couches) = asphalt casing in two layers. — S.N.C.F. Jonction de 2 tabliers = S.N.C.F. junction of two decks. — Chape en asphalte... à joints croisés = asphalt casing (mix : 100 kg asphalt putty, 8 kg refined bitumen) in two 8 mm layers with joints at right angles. — Chape de protection... à 150 kg de ciment = protective casing, fine gravel without sand mixed with 150 kg of cement.

ling does not hold water and makes it possible for it to drain out quickly through the gutters. Earth or clay embankments are therefore to be avoided.

The filling in materials should not damage the casings (S.N.C.F., F.S., Czechoslovakian Railways). Rolled materials are better than broken ones. According to the S.N.C.F. and the Czechoslovakian Railways pebbles or rolled gravel of 15-30 mm seems to be better than finer materials or sand which retains water.

According to the Viet-Nam Railways, the filling-in materials should be chemically neutral, and for the same reason the Czechoslovakian Railways avoid using slag.

3.34) *What do you consider is the average life of the casing of masonry and concrete bridges?*

The replies to this question are summed up in Plates 10, 11 and 12.

We will merely state that the values given for every type of casing differ considerably. This depends on the fact that the average life of the casings is influenced by many factors and consequently is very variable. This is the opinion held by the S.N.C.B. and the S.N.C.F. The latter states that the length of the effective protection given by old casings depends on their nature and the care with which they were made, on the number and siting of the drain outlets, on the slope carrying off the water towards these drains, on the nature of the filling-in between the spandrels, and above all, on large bridges, on the fatigue suffered by the parts they are protecting and to which they are attached (permanent compression, alternating stresses).

According to the S.N.C.F. the effective life of the original casings seems to be between 20 and 80 years.

The F.S. likewise, who no longer use mortar casings, recognise that some old cement mortar casings, and even lime mortar casings have a long life if they are not cracked by shrinkage and vibrations.

The length of life given for asphalt casings varies between 15 and 30 years.

The Viet-Nam Railways, however, think that if other conditions are favourable, they may last for 50 years.

This period is also given by the N.S. for casings made of gravel impregnated with pure Trinidad asphalt, which they have used in a few isolated cases.

In the case of multi-layer casings, the length of life mentioned varies from 10 years (N.S., J.D.Z.) to 30 to 50 years (Czechoslovakian Railways).

3.35) *Are there any types of bridges on which you consider there is no point in providing a casing?*

Most Administrations consider that it is necessary to provide a casing on all masonry or concrete bridges.

Sometimes in the case of very small bridges, for example aqueducts (S.N.C.B.) and tubular culverts (M.A.V.) a coat of mortar or a simple smoothing off of the cement takes the place of the casing currently used on larger bridges.

The S.N.C.F. and the F.S. do not use casings on overbridges with a watertight asphalt roadway, and in general when the design of the bridge is such that there is no fear of the effects of water on the vital parts that have to be protected. The C.F.F. consider it would be useless to apply a protective casing on reinforced or prestressed concrete railway bridges on which the track is laid direct (without ballast) on condition that the water can run off quickly and the concrete is of high quality.

The Czechoslovakian Railways consider it useless to provide a casing on the decking of bridges made of concrete prestressed in two orthogonal directions, where, as a result, there is no chance of any cracks occurring.

The R.E.N.F.E. think that casings are not necessary on reinforced concrete panels and slabs.

3.41) *What do you consider the minimum thickness under the sleepers of the layer of ballast on bridges in order to avoid damage to the casing due to the carrying out of work on the line and to local stresses due to trains passing over them?*

The minimum thickness of ballast under the sleepers varies between 15 and 60 cm.

The minimum of 15 cm is allowed on the S. N. C. V., the Viet-Nam Railways (under wood sleepers) and the N.S.

The Cameroons Railways, who require a thickness of 25 to 30 cm report that on a bridge where the ballast was only 15 cm thick nothing untoward had been noted.

The Viet-Nam Railways stipulate a minimum thickness of 20 cm under metal sleepers.

The French West African Railways, which use metal sleepers 7.5 cm high, stipulate 30 cm from the top of the sleeper, (22.5 cm from the bottom of the sleepers).

The S.N.C.F. and the Czechoslovakian Railways when necessary allow in exceptional cases a thickness of 20 cm, but the usual thickness is 25 cm. The Algerian Railways, the S.N.C.F., and the C.F.F. also stipulate a thickness of 25 cm. The S.N.C.F., however, state that it is of value to retain above the extrados of the arches a sufficiently thick mattress of earth to protect the casing and distribute the overload at the key stone.

The thickness of this mattress of earth should if possible be not less than 25 cm, which with the 25 cm of the ballast gives a minimum distance of 50 cm between the extrados of the arch and the underside of the track sleepers.

The C.P. mention 27 to 30 cm, the S.N.C.B. 30 cm (though they sometimes allow 25 cm in case of necessity).

The J.D.Z and the C.F.L. prescribe 30 cm; the O.T.R.A.C.O. and the Tunisian Railways 30 cm, and in addition a layer of gravel 10 cm thick to protect the casing and distribute the load and local dynamic effects; the M.A.V. 35 cm (or 25 in exceptional cases); the F.S. 40 cm for the decking and 50 cm on the arches (in case of need these thicknesses can be reduced to 30 cm only).

The Djibouti to Addis Ababa Railway prescribes 40 to 50 cm; the R.E.N.F.E. 60 cm of ballast, and between it and the casing, 1 m of filling-in material.

3.42) *Do you consider that the casing should be protected against damage of this sort* (*) *by an additional layer of concrete, ceramic tiles, or other materials?*

In general, cement casings are not protected by any additional layers (see Plate 10).

(*) i.e. deterioration due to maintenance work and to localised stresses resulting from running loads.

Only the « Chemins de fer Economiques » consider it safer to protect the casing on important bridges, especially the arches, where the filling-in is broken stone, by an outer casing 4 cm thick in concrete with a low proportion of cement.

The French West African Railways and the O.T.R.A.C.O. protect asphalt casings by an outer casing (see Plate 11).

The S.N.C.V. merely stated that the casing should be protected.

The S.N.C.B. and the Viet-Nam Railways on new bridges provide an additional layer of thin concrete 4 cm thick; the F.S. a coat of cement mortar 3 cm thick.

According to the F.S., the additional coat is intended not only to protect the casing against shocks, but should above all stop the volatilization of the light hydrocarbons contained in the asphalt.

Multi-layers casings are always protected by an additional coat (see Plate 12).

The M.A.V. protect the casing on almost horizontal surfaces by a 4 cm thick layer of concrete, and that on almost vertical surfaces by a line of bricks.

The D.S.B., the Finnish Railways, the C.F.F. and the Czechoslovakian Railways use a protective coat of lightly reinforced concrete.

The casing of plastic materials used by the C.F.L. is protected by an 8 cm thick layer of concrete.

As already stated (see No. 3.31) the casings of copper plates sometimes used by the D.S.B. are protected by steel sheets.

3.5) *When the masonry or the concrete is threatened with deterioration due to the insufficiency of the casing and when for operating reasons it is impossible to carry out essential repairs, have you done any waterproofing work to or through the soffit of the arches?*

If so, with what success?

The Administrations, which replied in the affirmative to this question, pointed out that this work was only carried out when absolutely necessary.

The Viet-Nam Railways merely state that they had done some waterproofing work starting from the soffits, but that this method had not always given the results hoped for.

The S.N.C.B. have carried out some tests, few in number but encouraging, by restoring certain bridges, for example the underground passages in stations, by grouting with a waterproofing product.

The Czechoslovakian Railways, when the masonry is not damaged, bind it again by using a water-repellent mortar which sets very quickly to a great depth, according to the methods used in underground passages.

Grouting through the soffits has been carried out on certain arches which were cracked right through, by the C.F.F., the F.S. and the Algerian Railways, who have also at times consolidated by means of truss rods, bridges treated in this way.

The S.N.C.F. use one of the following three methods of water-proofing to reduce the permeability of arches when operating conditions make it impossible to work upon them through the soffits :

1) Grouting with cement in the body of the arch through holes bored in the intrados; the permeability can be reduced by 70 to 90 %. It may happen, however, that even under slight pressure, the grouting will bring away loose parts of the casing;
2) Spraying on a cement coating after preparation of the surfaces and making drainage holes; this method may make it possible to do away with the guttering entirely;
3) Thorough repointing (7 to 10 cm) of the face. The reduction in permeability is a function of the kind of facing; it may amount to about 50 %.

The S.N.C.F. in addition has made use of grouting with plastic materials, in bridges with encased beams and bridges made of reinforced concrete. Such grouting has given good results.

The F.S. have successfully waterproofed an underbridge through the soffits. First of all, the mortar was removed from the walls and soffits and the surfaces cleaned by jets of water under high pressure. Then a coating of cement mortar was applied with a special waterproofing product in two 15 mm thick coats. On the soffits, a light trellis (or canvas) was inserted between these two coats.

This method made it possible to do away with the guttering completely. The F.S. think that the masonry will be slowly consolidated as time goes on by the salts which the rain water washes out of the ballast and deposits inside and above the arch and the walls, instead or washing them out.

This opinion contrasts with that of the D.S.B. according to whom « the water which remains in the masonry in the end leads to a destruction of the concrete, for example on account of alternate freezing and thawing ».

It should be pointed out that this alternation is not possible owing to climatie conditions, in the F.S. bridge dealt with above.

3.6) *To protect the outside surfaces of masonry work in stone, brick or concrete, do you use layers of mortar, paint or other special coatings? If so, please state what materials are used, together with their characteristics and specify in addition under what structural and local conditions you consider their use advisable.*

In general, the outside surfaces of masonry are not covered up unless for aesthetic reasons, but care is taken in selecting the materials used for the facing, the pointing is carefully done, and in the case of concrete masonry, the moulding is carefully done, and after removing the shuttering the surfaces are scraped down and made regular with a cement or mortar wash.

For some years, the D.S.B. to a certain extent has been painting the outside surfaces of concrete with a cement paint

known as « Cempesco ». This product, which is made in several attractive colours by the Danish Cement Works, makes the surface of the concrete more compact and even is partially water-repellent.

The C.F.L. coat the undersides of overhead bridges in reinforced concrete with an anti-acid product in order to reduce the porosity of the concrete.

With the same object, the F.S. and the Czechoslovakian Railways have used bitumastic paints. The Czechoslovakian Railways use galvanised sheet or flat or corrugated artificial slate smoke screens under parts of bridges particularly attacked by smoke.

The Viet-Nam Railways use a cement mortar coat to protect the exterior surfaces of masonry. The S.N.C.V. do the same, spraying on the mortar mechanically.

The Czechoslovakian Railways apply a sealing coat over the concrete which afterwards is painted with successive coats of colourless fluorides to prevent damp getting in.

The « Chemins de fer Economiques » generally render the face of the concrete with a coat of cement mortar.

The Djibouti to Addis Ababa Railway covers any damaged surfaces with a coat of cement mortar, and with the same object the C.F.F. use coats of cement mortar applied under pressure.

3.7) *What methods do you use to repair the damage listed under 3.1) above, such as, for example, grouting with cement, cutting out seams, prestressing, tie bars.*

Please describe the method used on your railway.

The S.N.C.V. and the Finnish State Railways did not answer this question.

The Cameroons Railways state that they have not had to undertake any such work, and the J.D.Z. that they have not had occasion to use the methods mentioned.

The O.T.R.A.C.O. merely mentioned the use of protective gabions or screens.

The French West African Railways replied that such repairs are rarely made, and in general it was preferable to remake the bridge, especially in the case of abutments which were built with lime mortars and poor quality sand.

The replies of the other Administrations mention methods which in general, are not used by themselves. In most cases, when repairing damage, use is made of methods resulting from a combination of several of the measures mentioned.

a) *Replacing defective masonry or brickwork :* (« Chemins de fer Economiques », Viet-Nam Railways, M.A.V., F.S., C.F.L., C.F.F.).

Generally, this measure is only used when the damage is not serious. The replacement takes place in stages.

b) *Consolidation of the masonry,* (especially the facing — C.F.F.) *by grouting with cement* (R.E.N.F.E., S.N.C.F., Algerian Railways, Viet-Nam Railways, F.S., C.F.L., N.S., C.P., C.F.F., Czechoslovakian Railways, Tunisian Railways).

c) *Replacing loose filling-in with weak concrete over which a casing is put* (C.F.F.).

d) *Use of metal tie bars or reinforced concrete.* (S.N.C.B., D.S.B., S.N.C.F., Algerian Railways, Djibouti to Addis Ababa Railway, Viet-Nam Railways, C.F.L., Czechoslovakian Railways, Tunisian Railways).

This method is used above all to remedy tilting of the spandrels. To do this, however, the C.F.F. prefer to replace rather than fill in.

The S.N.C.B. at the present time is using reinforced concrete trusses. These trusses are embedded in the masonry. If they are very long (72 m) they are made in several sections with prebending of the bars.

e) *Grouting with cement to fill-in cracks in the concrete or reinforced concrete.* (« Chemins de fer Economiques »).

f) *Reconstitution of damaged concrete* (D.S.B., S.N.C.F., M.A.V., F.S., C.F.L., C.F.F.).

This is a complicated job, which sometimes also requires grouting with cement.

g) *Cutting out seams.* (Viet-Nam Railways, F.S., C.F.L.).

This is done by drilling ordinary holes by the cracks or in two directions crossing each other and on the cross in relation to the cracks. High adhesion iron (Tor iron for example) is inserted in these holes, then cement mortar is grouted in. Such seams are used by the F.S. especially at the sharp ends of cross arches.

h) *Remaking the casing.*

This is a very costly job if the traffic is to be maintained. This method is probably used in certain cases by other Administrations who did not mention it. In this case it was mentioned by the S.N.C.B., M.A.V., F.S., C.F.F., Czechoslovakian Railways.

i) *Strengthening the arches and decking.* (S.N.C.B., D.S.B., R.E.N.F.E., « Chemins de fer Economiques », F. S., C.F.L., C.F.F., Czechoslovakian Railways).

This is generally done by adding a reinforced concrete covering, either below or above the arch or old decking.

l) *Getting rid of hollow places in the arches* (R.E.N.F.E., F.S.).

m) *Consolidation of cracked abutments and piers by jacketing them with reinforced concrete.* (« Chemins de fer Economiques », Djibouti to Addis Ababa Railway), or by using a steel ring encased in concrete on the upper part (M.A.V.) or not (F.S.).

n) *Consolidation of a cracked abutment by means of prestressed concrete.*

This method has been used by the N.S. The arrangements adopted are shown in Plate 14.

o) *Stiffening piers that get deformed too easily by reinforced concrete walls prestressed against the old masonry.* (F.S.).

p) *Repair from below.* (Viet-Nam Railways, F.S.).

q) *Consolidation of weakened and tilted piers by running in concrete with rails for reinforcement under the foundations.* (« Chemins de fer Economiques »).

r) *Construction of a reinforced concrete or concrete wall in front of* (« Chemins de fer Economiques ») *or around the foundations.* (F.S.).

This measure if often combined with those mentioned under m), and q) or s).

s) *Consolidation of the foundations by grouting with cement mortar.* (F.S.).

This method can be used when the ground is mainly gravelly and does not include any clay at all.

t) *Struts, arches, or trusses to bind the piers.*

In general, the Administrations merely mentioned the methods they had used, but the replies which are summed up in Plate 16, do not give many details, and in most cases throw no light on the succession of jobs that have to be undertaken in carrying out the repairs.

There were a few exceptions.

The Tunisian Railways for example described and illustrated by photographs the method followed in repairing the unloading arches of the bridge over the Oued Bou Hertma. The work was carried out as follows :

A temporary bridge was erected to isolate the arch to be repaired from overloads, and then the extrados and inside walls of the spandrels were laid bare. After

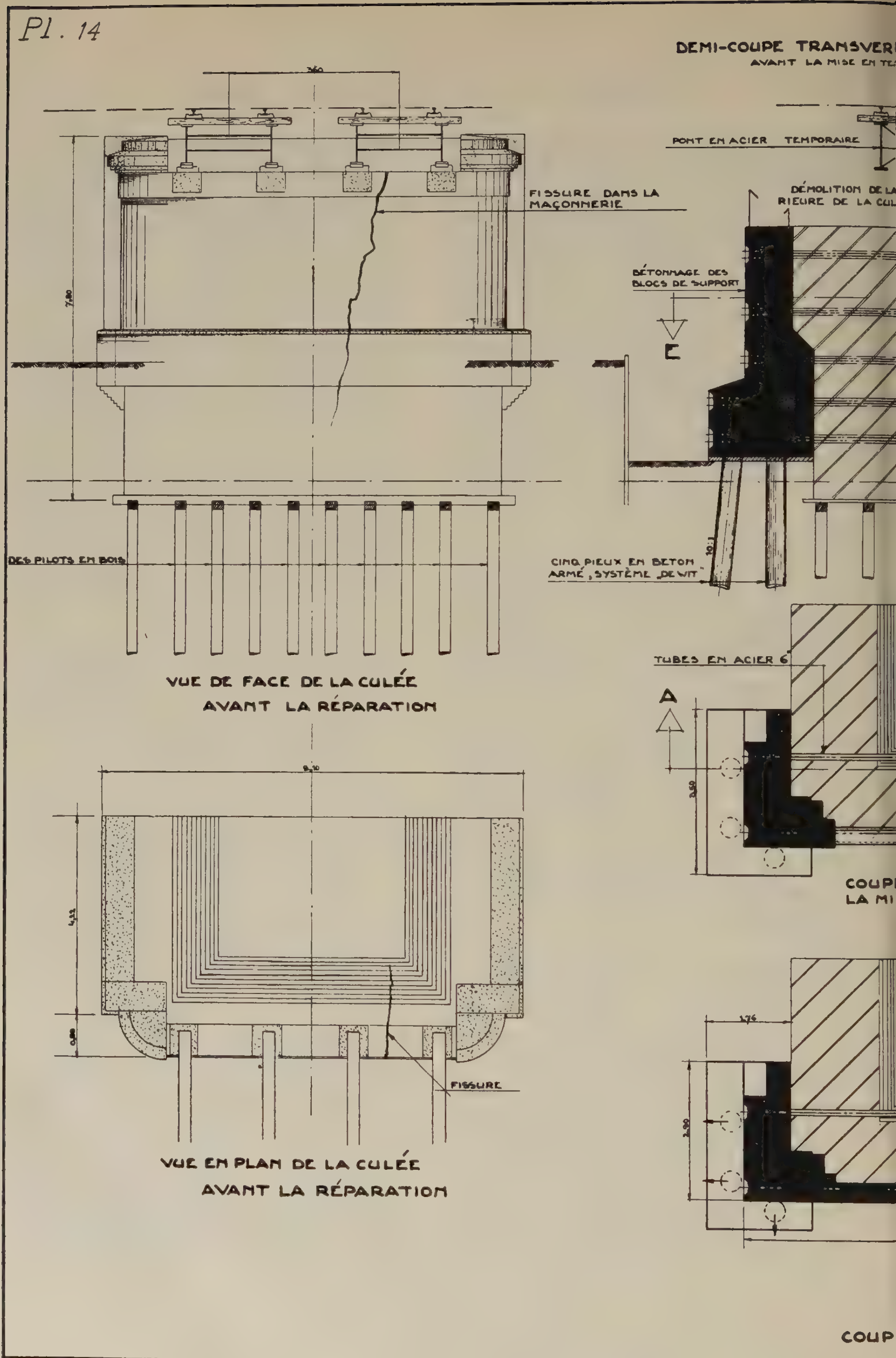
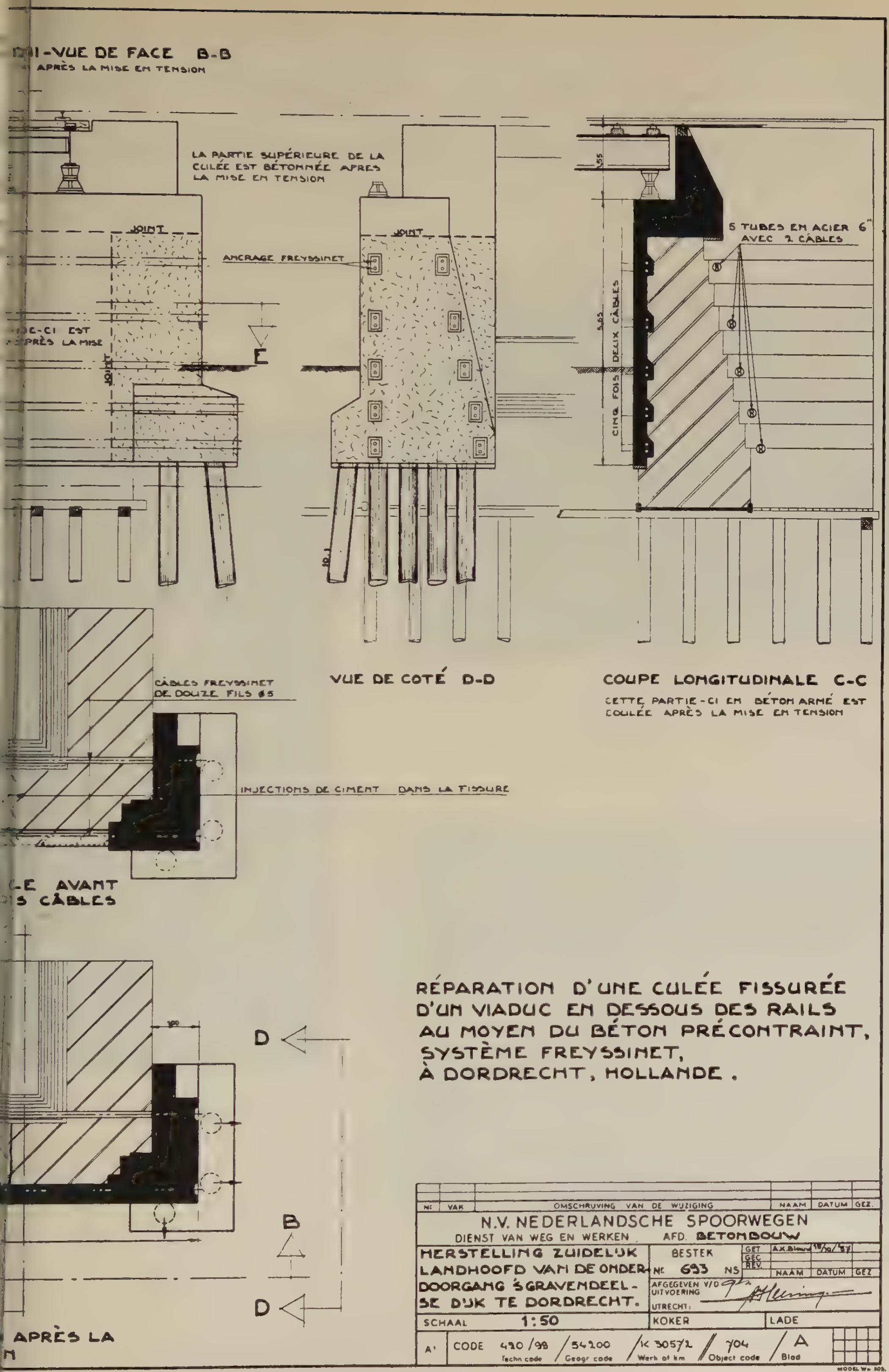


PLATE 14. — *N.S. : REPAIRING A CRACKED ABUTMENT BY MEAN*

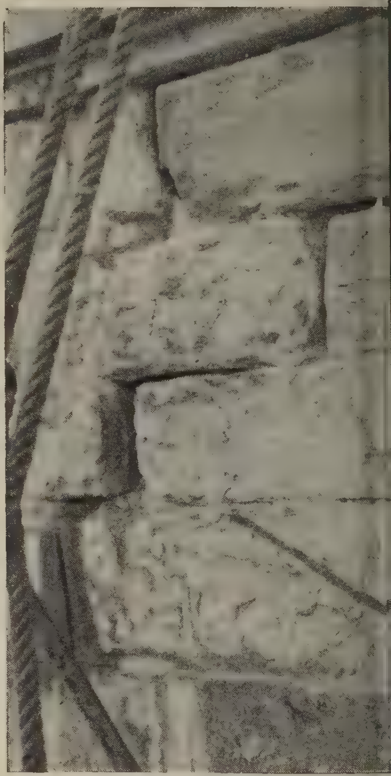


ED CONCRETE (FREYSSINET SYSTEM), AT DORDRECHT (HOLLAND).

PLATE 15. — *TUNISIAN RAILWAYS : REPAIRS TO THE FLOW A*

(CHEMI

1. View of the bridge.

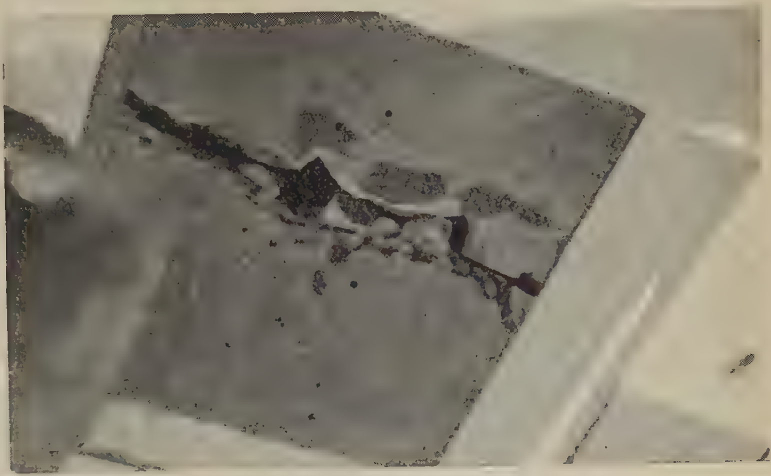


2. Cracks in the tympanum.

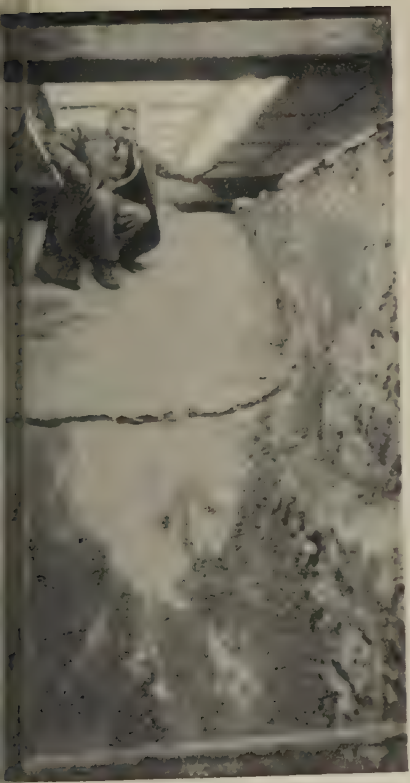
3. Detail showing the collapse of an arch-stone.

...BRIDGE OVER THE WADI BOU HERTMA ON THE TUNIS TO GHARDIMAOU LINE.

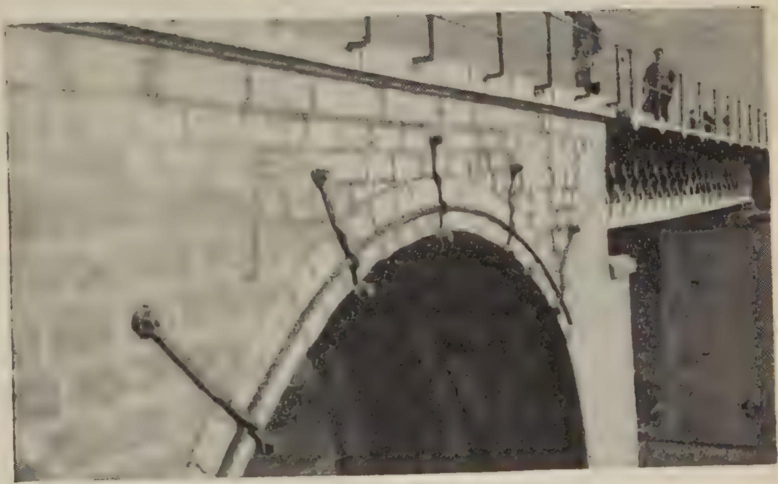
...NISIENS)



4. Rupture of extrados arch.



5. Rupture of extrados arch.



6. Fruss-rods of the tympanum arch - Ghardimaou side.

the masonry has been inspected, repointing was done, trusses were put in place, and cement was grouted in. After the grouting had set, the track was restored to its original position.

Plate 15 includes several photographs showing the damage found and the work undertaken.

The S.N.C.F., the F.S. and the Czechoslovakian Railways gave details about grouting masonry.

According to the S.N.C.F. the operations should be done in the following order :

1) Filling-in cracks, repointing the facing if necessary;
2) Drilling in the masonry, in successive stages, 0.05 to 0.09 m dia. holes at regular intervals to the proper depth;
3) Checking by compressed air or water under low pressure (1 g/cm^2) that the holes communicate with each other and with the cracks and hollows;
4) Drilling intermediate holes in order to assure such communication should the first drilling be inadequate;
5) Checking the new holes in the same way; at each stage, there must be communication with the upper stages to assure free drainage when grouting;
6) Testing to evaluate the hollows, if possible, examination of the possible losses to be feared through the ground;
7) Grouting with liquid cement (generally 50 kg cement to 50 l of water, if absorption is good) stage by stage.

Checking the filling by the sweating and drainage of water from the control holes. Then the same procedure is followed for the next stage above.

If the upper gutters are always kept, as they should be, in constant communication with the grouted parts, there should not be any excess pressure, and if the tubes are clean and open, the pressure should not exceed 1 kg/cm^2 at the grouting nozzle.

Particular care must be taken when large loose areas are known to exist or are suspected.

It is only when absorption is too small and perfect watertightness is required, that a second grouting is made under slightly greater pressure (2.5 or 3 kg).

If losses through the ground are suspected, the back of the masonry can be treated first of all by a thin mix inserted under very low pressure through the first holes drilled; the drilling is then completed after this has set, the checks made and the normal grouting carried out.

When the work is completed, auscultation of the masonry will reveal if there are any loose parts; or holes can be drilled to check the work.

Care must be taken in all grouting to avoid filling up the drains or outlets. Grouting must cease immediately there is the slighest fear that the draining system is getting block up.

The F.S. and the Czechoslovakian Railways who make use of similar methods, also lay down that the masonry must be washed with a jet of water before the cement mix is grouted in, and state that when the work is completed, the casings are remade when possible.

The Czechoslovakian Railways drill the grouting holes before any pointing is done.

* * *

The S.N.C.F. also gave some details about the methods used to restore concrete in poor condition.

The damaged surfaces are gone over with a hammer, and any reinforcements that have begun to corrode are completely removed. Then the reinforcements are cleaned by sand jet; any additional reinforcements that may be needed are put in position; the moulds are put into position by means of wedges and presses; the parts to be remade are washed by water under pressure; cement mortar is sprayed on (430 kg per m^3 of sand) in two layers 2 cm thick, at intervals of 1 to 2 hours between the layers, the period being shorter when the atmosphere is dry.

PLATE 16. — Résumé of the replies of the Administrations to questions 3.7, 3.81, 3.82, 3.91 and 3.92.

QUESTIONS :

3-7) *What methods do you use to repair the damage listed under 3.1) above, such as, for example, grouting with cement, cutting out seams, prestressing, tie bars?*
Please describe the method used on your railway.

3.81) *As on most railway lines there are some old masonry bridges, have you ever thought that it is necessary to check their strength as a result of the progressive increase in loads and speeds, or do you consider that a general examination of the condition of the bridge is sufficient?*

3.82) *Have you ever had to strengthen bridges simply to allow heavier loads than those estimated for at the time of construction? If so, please describe the types of reinforcement used.*

3.91) *When repairing the arches of bridges necessitating the partial destruction of the masonry, what steps do you take to assure proper solidarity between the old and new masonry, and to avoid abnormal distribution of the stresses?*

3.92) *When do you consider it advisable to undertake the partial reconstruction of masonry bridges, and when on the contrary do you think it better to demolish and completely rebuild?*

PLATE 16. — **Résumé of the replies**

Administrations	*3-7*	*3-81*
S.N.C.B. (Belgium)	To consolidate cracked bridges, metal or reinforced concrete trusses are generally used. Reinforced concrete trusses are most widely used. These are inserted into the masonry. If they are longer than 2 m, they are made in several sections and the bars bent in readiness In certain cases a complete inside facing of reinforced concrete has been made. It is sometimes necessary to replace the casing. This is a very costly job.	A general examina of such types of bri is sufficient provided made regularly. If deterioration o certain extent is not calculations are mad the stability of the arc
Nat. Light Railways Company (Belgium)	—	A general examina of the condition of bridge suffices.
O.T.R.A.C.O. Matadi-Leo Railway	Use of protective gabions.	There has not been increase in the load excess of the typical tr
D.S.B. (Denmark)	Remaking the faulty concrete by concrete spraygun, using pneumatic tools, (compressed air hammers and shears, sand jets, rough-rendering by spraying). Strengthening by adding additional reinforcements and grouting. Adding extra supporting piles, trusses, etc.	The D.S.B. do consider that a gen examination of the c dition of the bridg sufficient.
R.E.N.F.E. (Spain)	Elimination of hollows on the arches, or replacing masonry buttresses by flat plates in reinforced concrete. Making a new arch in concrete, using the old one as centering.	A general examinatio sufficient.
S.N.C.F. (France)	Remaking the joints, making drain outlets, remaking faulty concrete (with or without truss-rods) and frequently grouting with cement mortar. Canted spandrels are successfully treated by fitting trusses which are put under tension, following by grouting to fill in the gaps between the trusses and masonry.	In principle, a gen examination of bridges is sufficient. However a theore check of the stabilit carried out as soon bridge shows certain racteristic signs of fati

tions to questions 3.7, 3.81, 3.82, 3.91 and 3.92.

	3-91	*3-92*
	When the first rounds of brick have been replaced by reinforced concrete, cramps are provided to connect the reinforcement of the concrete to the sound masonry. These cramps are driven in to a depth of 15 cm.	If the deterioration is serious and affects the whole thickness of the arch, complete rebuilding of the arch is advantageous. Such reconstructions are avoided as much as possible by means of periodical maintenance which may include partial reconstruction or strengthening with reinforced concrete components.
	A reinforced concrete bearing plate to distribute the load is provided on the old masonry.	—
g.	Fitting of anchoring rods.	The O.T.R.A.C.O. considers it is easier and quicker to erect a new arch under the old one. It has never been necessary to do this however.
dinarily, but some- ling an additional concrete or rein- concrete bridge) or onal masonry — all strengthening or ng the wing and walls — reinforced te bearing plates to he load above the	Driving in irons, grouting. When possible, taking the load off the existing bridge. No steps are taken when it is merely a question of ordinary maintenance or strengthening small masonry bridges.	Old masonry bridges generally still have a long life provided they are fairly well maintained and strengthened.
ery few cases, it has necessary to stif- e structure by but- g the wing and flank	On certain small bridges, the extrados of the arch has been cleaned and hammered by adding stone wedges, and then the reinforcements were concreted.	Demolition and complete reconstruction is better. In arched bridges of more than 20 m span, strengthening may be advantageous.
	The surface to be repaired is carefully removed. Anchoring irons are arranged in place when the surfaces in contact will receive important tangential stresses. Proper distribution of the stresses is assured by caulking (matages) the joints for this purpose. In special cases expanding cement concrete has been used in the quoins.	Apart from exceptional cases of restoring to good condition bridges severely damaged during the war, partial repairs have always been adequate for remedying the damage occurring.

Administrations	*3-7*	*3-81*
Chemins de fer Economiques (France)	Remaking the masonry of the facing. Grouting with cement mortar to fill in cracks in a reinforced concrete deck. Consolidation of abutments that have been weakened and overturned by undermining due to floods; putting concrete reinforced with rails under the foundations and making a reinforced concrete wall in front of the foundations ; in addition repairing the vertical faces by covering them with reinforced concrete with anchorage.	A general examinati bridges is in prin sufficient. In ce doubtful cases c ations have been ma verify the strength.
Algerian Railways	Bridges showing cracks throughout have been consolidated by adding trusses and grouting with cement, which has also had the effect of restoring their watertightness (see 3.5).	It does not appear of much use to check closely the strengt old arched bridges the action of he overloads.
French West African Railways	Such repairs are rare; generally it is preferable to rebuild the bridge, especially abutments originally built with poor quality lime and sand mortar.	No.
Djibouti to Addis Ababa Railway	Rendered with liquid cement. Fitting trusses - jacketing with reinforced concrete any damaged piers. Making stops or buttresses of reinforced concrete.	General examinatio the bridge considere ficient to date.
Viet-Nam Railways	Repairing the underparts, additional supports or stays, replacing parts, grouting with cement (preferably quick setting to which SIKA has been added) adding new arch components in metal to strengthen the arches, tractive seams, anchorages and piers.	Bridges are systema ly checked when the are increased.
M.A.V. (Hungary)	Complete renewal of the casings. Replacement of defective bricks. Construction of a continuous supporting bank in reinforced concrete at the top of the piers and abutments. Adding a steel circle encased in reinforced concrete around the top part of any piles that are cracked or split vertically. Remaking the layer of concrete below iron beams carried out by a jet process after removing the remains of the old rendering.	In general, there is m an examination of general condition o bridge. If for any rea a static check calcul is made, it often ap from this calculation the arch is not st enough for the new h loads.
F.S. (Italy)	Replacing defective stones or bricks by degrees, consolidation of the masonry by grouting with cement, adding trusses and seams, remaking defective concrete, remaking the casings, reinforcing the arches by a new layer of reinforced concrete on the extrados of the old arch; elimination of hollow places in the arches, putting a steel hoop round the upper part of cracked piers, repairs from under the bridge, construction of a wall around the foundations, consolidation of the ground at the foundations by grouting with cement mortar.	In general, there is m an examination of general condition bridges.

...	*3.91*	*3-92*
...g the thickness ...tments of arched ...s and making ...rings outside the ...ipes).		
	To carry out work of this kind, the arches are put on centres and when necessary to balance the horizontal thrust, they are temporarily stayed at the level where these start by stops.	If the supports are in good condition, it appears better to repair the arches, in order not to run the risk of destroying the equilibrium that has already been attained. When the supports have also suffered serious damage, it is advisable to demolish the masonry down to the level of those parts which appear to be sound.
	—	No experience of any such case.
	Undermining deep in the joints to the ashlaring and making of casemates — Setting up of iron trusses — Ashlaring dividing up in reinforced concrete.	Partial reconstruction is only undertaken if the piers and foundations are in good condition; otherwise the bridge is completely rebuilt.
...nforcements vary ...ng to the kind of ...o be strengthened.	Energetic scraping and cutting away the exposed faces of the old masonry. Rendering the contact surface with mortar rich in cement. Deep anchorage of the connecting reinforcement before pouring the concrete.	Demolition and complete reconstruction are preferable when this does not upset the traffic and the amount of work to be done makes it necessary.
	If partial demolition of the arch becomes necessary, the M.A.V. demolish the whole arch and replace it by a new one.	See *3.91*
...hat are too easily ...ed are stiffened by ...ced concrete walls ...g against them.	Remaking the masonry has to be done in stages. The solidarity of the old and new masonry can be improved by grouting with cement. When large scale reconstruction has to be undertaken, it is necessary to take the load off, and to centre and stay the arches. In general in such a case it is preferable to rebuild complete segments of the arch including the damaged areas.	The choice between partial reconstruction and demolition and rebuilding depends on the importance and nature of the damage found and the causes which led to it. When the arches show serious damage owing to subsidence of the foundations, in general the bridge should be demolished and completely rebuilt.

PLATE 16. — **Résumé of the replies**

Administrations	*3-7*	*3-81*
C.F.L. (Luxemburg)	Replacing defective stones. If the defects are somewhat general, scouring after (torcrétage) of the masonry according to need. Reinforcement by means of a reinforced concrete curtain. Seams with anchorage bolts or ties with cement grouting. Reconstitution of the concrete by pickling, scouring (torcrétage) and cement grouting.	Usually a general exa ation of the bridg sufficient.
N.S. (Holland)	Grouting with cement and prestressing have been used to repair hollows in the piers. Wing walls have been tightened up by prestressing against the abutments.	In isolated cases, test have been mad continuous arches in forced concrete. stresses caused by ations in tempe were much greater those due to the m loads.
C.P. Portugal	Cement grouting is generally used.	So far it has not necessary to mak complete check of strength of mas bridges.
C.F.F. (Switzerland)	Replacing loose filling-in by thin concrete over which the casing is laid (with the object of avoiding the spandrels breaking away). — Grouting and sometimes anchorage of the facing with irons. — Grouting with cement in porous or washed out concrete and masonry. — Making or remaking the casings. — Replacing defective stone by stages. — Repairing damaged concrete facings, derusting the reinforcements and rendering with cement mortar under pressure. — Demolition of the concrete, laying transversal reinforcements, and reconcreting the beams. Connecting the two abutments by trusses (if necessary prestressed trusses).	As old masonry br were always conserv even a considerabl crease in the ove only theoretically inc the stresses by 3 kg/cm^2
Czechoslovakian Ministry of Transport	Grouting with cement. Anchoring trusses tie bars.	Detailed examinati the strength is nece in the case of segm arches of average or span.
Tunisian Railways	Grouting with cement combined sometimes with adding trusses or tie bars, or again banding with reinforced concrete forming a ring outside the masonry.	A general examin of the exterior o bridge is sufficient.
J.D.Z. (Jugoslavia)	Have not had occasion to apply any of the methods mentioned.	A general examinati the condition of arches is sufficient.

[...]strations to questions 3.7, 3.81, 3.82, 3.91 and 3.92 *(continued).*

	3-91	*3-92*
	The C.F.L. reinforced the arches of a viaduct by a reinfroced concrete trough above the extrados connected by anchorages to the existing masonry. The soffit was protected by a concrete shell applied by cement gun over an iron trellis. The C.F.L. affirm that it obviously is not possible to get any exact idea of the distribution of the stresses.	The partial reconstruction of masonry arches is advantageous when the damage is not very great compared with the size of the bridge. In the opinion of the C.F.L., there is always a way avoiding complete rebuilding of the bridge because the damage can be stopped by adding protective concrete to the defective masonry or reinforcing the arch by a shell over either the soffit or the extrados.
	Unknown.	Complete rebuilding was necessary in only one case, caused by subsidences due to coal mining. Masonry arches are rare in Holland.
	No work of this kind has been done.	In general it is considered preferable to rebuild.
[...]placing loose filling-in [...] reinforcement which [...] not aimed at but is [...]ective. [...] few rare cases, a new [...]h has been concreted [...] the existing arch.	During local repairs the joints are very carefully arranged so as to put the new stones under pressure. In the case of more extensive repairs the arch has to be centered. They have not risked using expanding cement.	The same criteria have been adopted as when strengthening metal bridges (see *2.92*).
[...] : the work of reinfor[...]ment carried out has [...]ways been necessitated [...] other reasons. [...]certain cases a reinfor[...]g arch has been added [...] the soffit of the old [...]dge.	No steps are taken when it is question of local and slight demolitions. If the demolitions are more extensive, adequate shoring is provided. The work is carried out either in segments, or in layers (bricks) The surfaces in contact with the old masonry are treated with dry mortar. Expanding concretes have not yet been tested.	Partial reconstruction of an arch is advantageous so long as the deformation of the arch is not excessive and provided that it is possible to key the reinforcing concrete into the existing masonry in order to obtain a good bond. Complete rebuilding is undertaken when the arches have seriously deteriorated or cracked, especially when this is due to subsidence of the foundation ground.
[...]o data on which to base [...] reply.	No data on which to base a reply.	No data on which to base a reply.
[...]o.	Have not had occasion to undertake any work of this kind.	Each particular case should be examined on its own merits before coming to a decision.

In this way, it is possible to restore the beam to its original condition, or to make it thicker if the original reinforcements or those now added are too close to the surface.

When only a small area has to be remade, special precautions have to be taken to prevent all the new mortar from coming off.

The thickness of each coat is then generally less than 2 cm. The mix is applied in several coats (3 for example), usually with an interval of 24 hours between each coat. To begin with the surfaces have been very carefully prepared by cleaning by sand jet and roughing up, so that the new cement can key in well.

The methods described by the other Administrations are very similar.

The D.S.B. has repaired 250 bridges by this method since 1928, and in certain cases has directly strengthened bridges by adding to the reinforcement.

The F.S. have recently tested special adhesives between the old and new concrete. These tests are too recent for their results to be known.

3.81) *As on most railway lines there are some old masonry bridges, have you ever thought that it necessary to check their strength as a result of the progressive increase in loads and speeds, or do you consider that a general examination of the condition of the bridge is sufficient?*

As old masonry bridges were never bold in design, but of ample proportions in relation to the low safety loads formerly adopted, their actual weight is very high, and an increase, even a considerable one, in the overload is only of secondary influence.

In addition these bridges include components which were not taken into account in the calculations (spandrel-walls, superstructure) which relieve the arches considerably (C.F.F.).

As a result, up to the present, a general, regular examination of the condition of these types of bridges has usually been considered sufficient, except by the D.S.B. who make examinations when the calculations are made to verify the actual condition of the bridge, and the Viet-Nam Railways, who make a systematic check of all bridges when the loads are increased.

It has been found, however, that an increase in the loads and speeds has speeded up deterioration wherever this was already noticed. Consequently, although no systematic analysis has been carried out for all the bridges, calculations for verifying the stability have been made in isolated doubtful cases of bridges showing signs of characteristic fatigue, or deterioration of a certain extent, or less favourable resistance conditions.

The Czechoslovakian Railways recommend detailed examination of the resistance conditions for arches of reduced height of average and large span.

The N.S. have carried out load tests on arches made of reinforced concrete; but it was found in this case that the stresses due to variation in the temperature were much more important than stresses due to the moving load.

3.82) *Have you ever had to strengthen bridges simply to allow heavier loads than those estimated for at the time of construction? If so, please describe the types of reinforcement used.*

Most of the Administrations answered this question in the negative, and those Administrations who reported certain work of strengthening undertaken with the sole objective or allowing heavier loads, pointed out that these were exceptional cases.

The D.S.B., the F.S. and the C.F.F. have at times concreted a new arch onto the existing arch; the Czechoslovakian Railways in certain cases have made a reinforcement arch at the soffit of the old bridge.

The F.S. have reinforced piers by reinforced concrete walls prestressed against

the old masonry. This work was undertaken with the object of stiffening the piers which were too easily deformed, and thus preventing the arches from cracking.

The « Chemins de fer Economiques » report cases of increasing the thickness of the piers of arched aqueducts and the making of concrete rings on the outside of the air channels.

Sometimes, the increase in the loads has necessitated strengthening or renewing the wing walls or head walls (D. S. B., R.E.N.F.E., F.S.).

In certain cases, the D.S.B. have put reinforced concrete plates under the ballast, with the object of distributing the load; in this way the weak part of the bridge is not overloaded.

3.91) *When repairing the arches of bridges necessitating the partial destruction of the masonry, what steps do you take to assure proper solidarity between the old and new masonry, and to avoid abnormal distribution of the stresses?*

The Finnish State Railways, the « Chemins de fer Economiques », the French West African Railways and the J.D.Z. did not give any reply to this question (see Plate 15).

The N.S., the C.P. and the Tunisian Railways, had nothing to report; the Cameroons Railways have no arches on their system; the M.A.V. do not undertake partial demolition.

From the replies received from the other Administrations, it appears that the remaking of the masonry is generally done in stages; with the object of assuring solidarity between the old and new masonry; it is necessary to pickle the surfaces to be treated very carefully, as it must be perfectly clean, in proper condition to take the mortar, damp but not with any water laying on it. Anchoring irons are also suitably arranged in order to improve the connection between the old and new masonry, when the surfaces in contact will receive important tangential stresses.

As long at it is merely a question of remaking small areas, sufficient of the old is retained to assure the solidarity of the two, counting on the fact that in time the abnormal stresses will be balanced out by the plastic adaptations (D.S.B., F.S.).

Solidarity between old and new masonry can be improved by grouting with cement (F.S.).

In every case the joints must be very tight in order to put the new stones under pressure (C.F.F.).

In the case of large scale rebuilding or even reinforcing, special precautions must be taken to assure proper distribution of the stresses.

The S.N.C.F. assures this proper distribution by jagging certain joints for this purpose. The S.N.C.F. in some special cases has even made use of quions made of expanding cement concrete to assure suitable compression of the new masonry added.

In this connection, it may be pointed out that none of the other Administrations make any mention of using expanding cement, and the C.F.F. and Czechoslovakian Railways answered that they have not yet tried it.

The D.S.B., Algerian Railways, F.S., and Czechoslovakian Railways point out that when large scale remaking has to be undertaken, it is necessary to use centering for the arch.

The F.S. generally prefer to rebuild complete transversal segments of the arch including the damaged areas. This work involves taking off the load, centering and shoring up the arch.

When strengthening operations are being carried out, if it is not possible to take the load off the existing bridge, the unequal distribution of the stresses must be taken into account when fixing the dimensions of the reinforcement.

The R.E.N.F.E. for example strengthened the brick arches of the Français bridge (Madrid to Irun line) with concrete arches, and made these latter sufficiently large to take the overload on their own.

The C.F.L. reinforced the arches of a viaduct that had cracked longitudinally and deteriorated at the soffit by a reinforced concrete trough above the extrados connected by stays to the existing masonry (fig. 19).

3.92) *When do you consider it advissable to undertake the partial reconstruction of masonry bridges, and when on the contrary do you think it better to demolish and completely rebuild ?*

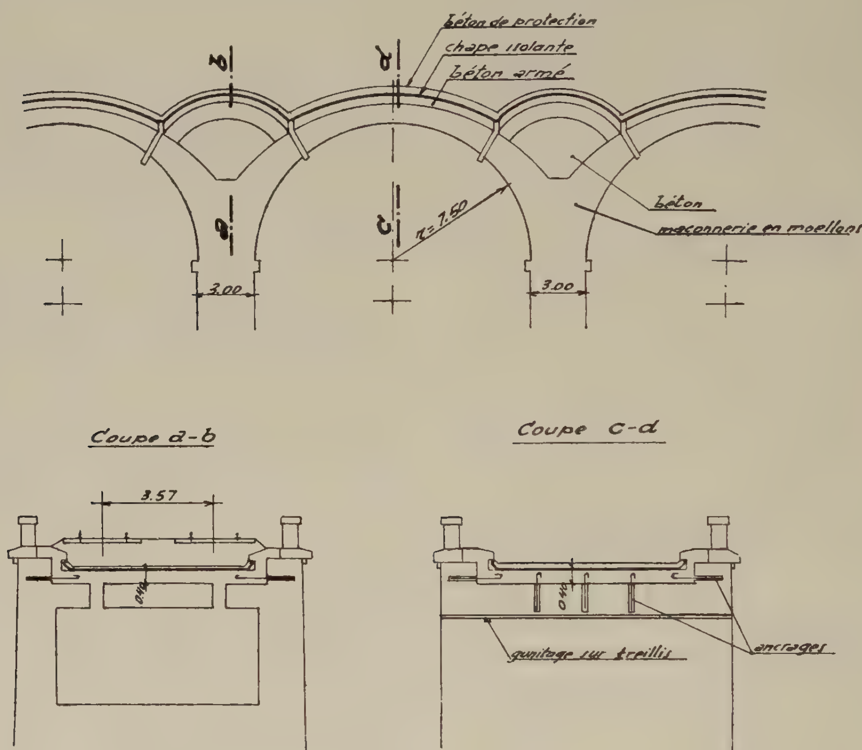


Fig. 19. — *C. F. L. :* Reinforcement of a viaduct.

N. B. — Béton de protection = protective concrete. — Chape isolante = isolating casing. — Béton armé = reinforced concrete. — Maçonnerie en moellons = stonework. — Coupe = section. — Gunitage sur treillis = cement gun casing on trellis. — Ancrages = anchorage.

The soffit was protected by a concrete shell applied by cement gun over an iron trellis suspended from the existing masonry. The C.F.L. do not think it is possible to get an exact idea of the distribution of the stresses as a result of this method; it is certain, however, that the old arches have been considerably relieved as regards the moving loads.

The opinions of the Administrations who answered this question differed remarkably (see Plate 16).

According to some Administrations, it is not possible to give any general rule (D.S.B., J.D.Z.); other Administrations think it is usually better to rebuild the bridge completely (M.A.V., C.P.), whilst the S.N.C.F. states that partial reconstruc-

tion has always been enough to remedy any damage, apart from exceptional cases of restoring bridges severely damaged during the war, when the remaining portions of the arches and their supports were too badly damaged to be retained with safety.

The replies of the Administrations, who decide according to the merits of each particular case whether to reconstruct partially or demolish and completely rebuild, are very interesting.

These replies show that the main factors which have to be taken into account when coming to a decision about the partial reconstruction of a bridge are :

a) the importance of the part reconstruction to be carried out;

b) operating requirements;

c) the nature of the damage noted and its cause.

Obviously, partial reconstruction is the more advantageous, the smaller the part concerned. In this connection, it should be noted that according to several Administrations, good periodic maintenance and the carrying out of limited reinforcements can in most cases obviate the need for complete reconstruction.

Operating requirements may in certain cases prevent the complete reconstruction of a bridge and oblige the Administrations to carry out work to reconstruct and reinforce the masonry even though this will be more costly than complete rebuilding.

In other cases, when it is known that more important work will have to be carried out at a future date (for example rectification of the layout), temporary measures of limited extent may be expedient.

The nature of the damage may be the determining factor.

According to the Algerian Railways, for example, the first thing to worry about is the stability of the supports.

Provided these are in good condition, it is better to repair the bridge, in order not to risk destroying the equilibrium already obtained.

When on the contrary the supports are seriously damaged and there is doubt regarding their stability, it is advisable to demolish the masonry down to the level of the parts which appear to be sound.

The Djibouti to Addis Ababa Railway is of the same opinion, and in the same way the Czechoslovakian Railways consider that bridges should be completely rebuilt when there are serious cracks in the arches due to subsidence of the foundations.

In general, the F.S. also completely rebuilds in such cases, but at times they have successfully consolidated the ground and then partially rebuilt the arches.

* * *

4. Inspection and maintenance of metal, masonry and concrete bridges and viaducts.

4.11) *Has your Administration created any mobile gangs specialising solely in the inspection and maintenance of metal bridges and other such gangs specialising in masonry and concrete bridges, or else gangs dealing with both types of bridges?*

Are these gangs also responsible for bridges over the railway?

The S.N.C.V., the Finnish State Railways, the « Chemins de fer Economiques », the Algerian Railways, the Cameroons Railways, the French West African Railways, the C.F.L. the Damas-Hama Railway and the Tunisian Railways have no mobile gangs specialising solely in the inspection and maintenance of bridges.

The N.S. have a small number of qualified men specialising solely in small repairs to movable bridges, numbering 164. There is about one man per movable bridge.

The S.N.C.B. reports that they still have some gangs dealing with small maintenance jobs on bridges on certain lines, where road access is difficult. The S.N.C.B. is trying to suppress the need for such gangs completely.

The Matadi-Leo (O.T.R.A.C.O.) Railway, the Viet-Nam Railways, the F.S., the C.P., and the Jugoslavian Railways have one or several gangs specialising solely in the maintenance of metal bridges.

In 1928, the D.S.B. formed a special gang for carrying out work with cement gun, but at the present time, is intending to suppress this gang, as there is no economic advantage in retaining it.

The Lower Congo to Katanga Railway, the M.A.V., the C.F.F., and the Czechoslovakian Railways have gangs dealing with all bridges, whether of metal, masonry or concrete.

The R.E.N.F.E., the S.N.C.F. and the Djibouti to Addis Ababa Railway have specialised gangs, some dealing with metal bridges, others with masonry or concrete bridges.

The S.N.C.F. also has three gangs specialising in raising overbridges to bring them in line with the electrification gauge, one gang regulating the supports of metal bridges, and two gangs for applying the bitumastic or rubber products used in the maintenance of masonry and concrete bridges.

Most of the Administrations gave no reply regarding the maintenance of overbridges, or else stated that this was not their business.

The S.N.C.B., R.E.N.F.E., S.N.C.F., M.A.V., F.S., and C.F.F. on other hand replied in the affirmative.

4.12) *What is the average size of such gangs? How many bridges is each gang normally responsible for, and what is the total length of such bridges?*

Do these figures correspond to a normal standard, and if so, what standard?

The average size of the bridge maintenance gangs varies. There is a minimum of three men and a maximum of 40 with one or several foremen. Obviously most of the Administrations have classified as a « gang » all the men dealing with the maintenance of bridges in a district, and not the group of men who deal separately with certain jobs (see Plate 17).

This is why the numbers given as the average size of the gangs is of little value.

For example the C.F.F. have three gangs consisting of 9, 14, and 21 men respectively, and the F.S. 14 gangs with a varying number of men, from 14 up to 40.

In general, there are no regulations concerning the number or length of bridges in the charge of each gang. On the contrary, to arrive at the numbers in the gangs account is taken of the tonnage of the existing metal bridges, the probable reconstruction work, and (for gangs working on both metal and masonry bridges) the length of the other railway bridges to be maintained.

On the C.F.F., who in their reply gave the number and length of the existing bridges in the three regions of their railways the average number of bridges per man of the gangs is approximately 90 bridges (including 18 overbridges) and the average length of the railway bridges is 1 596 m, it being stated that bridges with 2 or more tracks have been converted into single track bridges for this purpose by multiplying the length of the bridge by the number of tracks.

This average length is considerably higher than that given in the replies received from the Lower Congo to Katanga and Viet-Nam Railways. The gangs of these Administrations are in fact responsible for some 2 000 or 1 500 to 2 000 m of bridges, i.e. 154 and 75 to 100 m respectively per man.

On the Czechoslovakian Railways, the average length of bridge per man of the gangs is about 430 m, and on the Jugoslavian Railways 500 m.

On the other hand, the average number of bridges per man of the gangs on the F.S. is 136, and the average length of the bridges 2 623 m.

These values are considerably higher than those given by the C.F.F.; what is

still more remarkable is that the gangs on the F.S. deal solely with metal bridges.

— The replies given to question 4.12 by the S.N.C.F. and the Czechoslovakian Railways are particularly interesting.

The Czechoslovakian Railways have two types of gangs : the district gangs which are responsible in particular for the maintenance of the bridges and consist at most of 6 men, and the regional gangs who are responsible for carrying out more important general repairs. The size of the regional gangs is on the average 10 men.

The district and regional gangs deal with both metal and masonry and concrete bridges.

The S.N.C.F., on the contrary, only has small specialised gangs.

The gangs dealing with metal bridges consist of 4 to 7 men, the other mobile gangs consist on the average of only 3 men.

The reply of the S.N.C.F. is particularly interesting as regards the output of these gangs.

The S.N.C.F. does not make each gang responsible for a given number of bridges; each of them is fully occupied according to an annual programme drawn up at the end of the previous year; the order in which the work is to be done is based on the gravity of the damage ascertained.

The number of bridges dealt with depends on the importance of the repairs, the working conditions (periods when the traffic is stopped), accessibility of the working sites; the number and the total length of the bridges vary considerably therefore from one year to another and from one gang to another.

Purely as an indication, the S.N.C.F. gave a few details to give some idea of the position; the following outputs must not be taken as the standard productivity, because a programme may include small, average or large bridges, and there may be considerable differences in the amount of work to be done on bridges of the same size.

Repairs to bridges, output per gang and per year (as an indication only) :

Small bridges (1 to 5 m span)	16 double track bridges, total length about 70 m.
Average bridges (up to 10 m)	11 double track bridges, total length about 80 m.
10 to 100 m long bridges	5 double track bridges, total length about 150 m.
100 to 200 m long bridges	3 single track bridges, total length about 500 m.

It can be estimated that the gang specialising in regulating the supports deals with 40 to 50 bridges a year.

These data cannot be compared with those received from other Administrations considered above, seeing that the S.N.C.F. refers to the work done by each gang, whereas with the other Administrations it is a question of the number or length of bridges for which each gang is responsible on the average for inspection and maintenance purposes.

4.13) *What movable machinery, tools and equipment is placed at the disposal of the gangs? On what basis are such tools allocated? What rail and road vehicles are at their disposal?*

The equipment of the gangs responsible for the maintenance of metal bridges usually includes a compressor, complete equipment for rivetting, screw-jacks, hand jacks, hand drills, and oxyacetylene welding equipment (see Plate 17).

The gangs of certain Administrations are also equipped with generating sets, electric welding outfits, electric drills (R.E.N.F.E., S.N.C.F., Djibouti to Addis Ababa Railway, Viet-Nam Railways, F.S., C.F.F., Czechoslovakian Railways, Jugoslavian Railways).

The gangs of the Lower Congo to Katanga Railway, Matadi-Leo Railway, and Djibouti to Addis Ababa Railway have paint spraying equipment.

Administrations	*Number and size of mobile specialist gangs allocated to bridge maintenance*							*Leng of bri fo whic eac gang respon*
	metal		*masonry and concrete*		*all types*		*total number of men*	
	number	*size*	*number*	*size*	*number*	*size*		
S.N.C.B. (Belgium) . . .	—	—	—	—	(1) ?	(1) ?	?	—
Lower Congo - Katanga Railways	—	—	—	—	1	1 European 12 native workers	13	2 kr
Matadi - Leo Railway (O.T.R.A.C.O.)	1	1 European 15 workmen	—	—	—	—	16	—
D.S.B. (Denmark) . . .	—	—	(2) 1	3-4 workmen	—	—	3-4	—
R.E.N.F.E. (Spain) . . .	?	1 foreman 4 workmen	?	?	—	—	70	—
S.N.C.F. (France) . . .	15	4 to 7 men	1	3 men	—	—	—	—
Djibouti - Addis Ababa Railway	1	1 foremen 3 workm. or assist. 5 labourers	7	1 mason 5 labourers or assistants	—	—	51	—
Viet-Nam Railways	?	20 men	—	—	—	—	—	1,5 to

...rations to questions 4.11, 4.12 and 4.13.

Equipment given to mobile gangs			*Remarks*
...Machines, tools, equipment	*Vehicles*		
	rail	*road*	
...used by masons, painters, ...es, and for making concrete ...concrete forms.	4 wagons : — office and canteen, — materials, — tools, — timber for forms.	—	(1) These gangs deal with small maintenance jobs on certain lines difficult of access by road. The S.N.C.B. is endeavouring to do away with them completely.
...ment for painting and paint ...ing; equipment for rivetting; ...ressor, forge, hand tools.	1 service vehicle for Europeans, 1 vehicle for natives, 2 wagons for tools and materials.	—	—
...es, hammers, rivetters, winches, ..., paint spray guns, compressor, ...es.	1 service wagon.	—	—
...pressor, cement gun, sand jet ...ment, injector, compressed air ...ner, pipes, scaffolding.	Special trolleys.	—	(2) This gang was created in 1928 specially for doing concrete work with a gun. The D.S.B. intend to do away with it.
...necessary hand tools, generator ...compressor and equipment for ...ing as required.	—	—	—
... maintenance gang for *metal ...es* is equipped with : pneumatic ...ment for rivetting, reaming and ...ng, oxy-acetelyne torches, a ..., air compressor set, or a ...rator set. ...ntenance gangs for *concrete ...es* are equipped with : a 32 H.P. ...compressor, cement gun equip...t, jagging and perforating ham... and all equipment needed for ...ting.	1 repair shop wagon, 1 motor equipment wagon, 1 dormitory - canteen wagon, 1 dormitory-workshop wagon, 1 scaffolding wagon, 1 stores wagon.	—	On the S.N.C.F. as a whole, there are also : 3 gangs specialising in raising overbridges in order to bring them in line with the « electrification » structure gauge. 1 gang specialising in the adjustment of the supports of metal bridges. 2 gangs specialising in grouting with bituminous and rubber products.
... gangs working on metal bridges ... equipped with compressors, ...rating sets, oxy-acetylene and ...welding, forges, rivetting ham...s, drills, sanders, paint spray...s, etc.	1 repair shop wagon, 1 service wagon for the gang foreman, 1 dormitory wagon.	—	The mason gangs at the same time assure the maintenance of scattered buildings.
...npressor, arc welding set, small ...tric generator, pneumatic ham..., pneumatic equipment for rivet..., cutting, drilling, etc.; oxy...ylene welding equipment, hand ...s, winches, hoists, jacks.	1 stores wagon, 1 wagon fitted with bunks, 1 special wagon for the compressor.	—	—

PLATE 17. — **Résumé of the replies**

Administrations	*Number and size of mobile specialist gangs allocated to bridge maintenance*							*Le of b f wh ea gan respe*
	metal		*masonry and concrete*		*all types*		*total number of men*	
	number	*size*	*number*	*size*	*number*	*size*		
M.A.V. (Hungary) . . .	—	—	—	—	?	variable	variable	—
F.S. (Italy)	14	1 foreman 1 to 3 assistants 15 to 40 Workmen	—	—	—	—	300	ave 5.6
C.P. (Portugal)	?	variable	—	—	—	—	variable	—
C.C.F. (Switzerland) . .	—	—	—	—	3	9, 21, 14 men including the foreman	44	ave 23.4
Czechoslovakian Railways	—	—	—	10 men (regional gangs) 6 men at most (local gangs)	—	—	1 300	30 3 1
Jugoslavian Railways . .	?	?	—	—	—	—	—	—

istrations to questions 4.11, 4.12 and 4.13 *(continued).*

Equipment given to mobile gangs			*Remarks*
Machines, tools, equipment	*Vehicles*		
	rail	*road*	
tools and equipment are based experience to date.	Living wagons, Wagons for examining railway bridges, Railcars.	—	The composition of the gangs is based on experience to date. The size is adjusted to needs.
tric generating set, equipment oxy-acetylene welding, compres- and pneumatic equipment for ting, reaming and drilling, hand s, jacks, hoists, etc.	Wagons for stores, repair shop, dormitory-canteen, Cranes wagons.	yes	On the whole of the F.S., there are 4 067 metal bridges. The combined length of these bridges is 78 684 m.
bile workshops and compressors the corresponding pneumatic pment.	—	—	—
ding equipment, compressor, erator set, electric and hand s, grinders, blowlamps, complete tting equipment, jacks, hoists,	Repair shop wagons, Store wagons, 8 crane wagons of 2.6 to 25 t capacity	no	Existing railway bridges: (*number* / *combined length*) Metal bridges and mixed beams . . . . 488 / 18 399 m Reinforced or prestressed concrete bridges and encased beams . . . . 1 442 / 26 780 m Masonry arch bridges . 1 228 / 25 063 m Total. . . 3 158 / 70 242 m There are also 814 overbridges.
regional gangs are equipped : mobile electric power station, pressors, drills, electrical and hanical tools, rivetters, mechan- punches, equipment for driving s, etc.	Service trains.	lorries and motors	The regional gangs carry out the most important general repairs. The length of bridge assigned to gangs is not fixed.
ompressor, welding equipment, tric drill, jacks, pneumatic and d tools for rivetting, forge, folding, etc.	2 covered wagons, a small wagon, a hand trolley.	—	—

Most of the Administrations replied that their mobile gangs are supplied with workshop-wagons, store-wagons and dormitory-canteens-wagons.

Certain Administrations also have travelling cranes for the use of gangs when necessary (F.S., C.F.F.).

The equipment of the gangs maintaining masonry and concrete bridges generally includes : compressor, cement-gun, special hammers and drills, and all the material required for grouting.

The regional gangs of the Czechoslovakian Railways are also equipped with the tools needed for pile-driving.

4.21) *Has the bridge maintenance department any workshops? If so, how many men are employed in them?*

4.22) *How are they equipped with machines and tools, and on what basis? What rail and road vehicles are at their disposal?*

4.23) *Is any special regime in force in these shops concerning their organisation and working?*

Certain Administrations which have one or several gangs specialising in the maintenance of bridges replied that they do not have special shops for this same purpose : S.N.C.B., Lower Congo to Katanga, Matadi-Leo Railway, D.S.B., Djibouti to Addis Ababa Railway (see Plate 18).

The Czechoslovakian Railways replied that they have no fixed repair shops, but that their maintenance services have at their disposal auxiliary mobile repair shops in which the men responsible for inspection can do any work required.

These auxiliary repair shops have permanent way service trains at their disposal equipped with all the necessary tools. They do not have transport units of their own either by road or by rail.

The meaning of this answer is not very clear.

Perhaps, these auxiliary repair shops are allocated as required to the regional gangs (see No. 4.12).

The F.S. and C.F.F. bridge gangs each have their own small fixed repair shop at which the equipment is serviced, as well as a certain amount of alteration and repair work done.

The following Administrations have repair shops apart from the bridge gangs :

One of the Regions of the S.N.C.F. has a shop used to machine the parts needed by the mobile gangs of the region (staff : 4 men).

The Viet-Nam Railways have a few small shops. The staff of these shops is very small (only 3 or 4 men) but can be increased when necessary by men from the mobile gangs.

The C.P. answered that they have a repair shop, but did not give any details.

The R.E.N.F.E., M.A.V. and Jugoslavian Railways have serveral fixed repair shops, some of which are highly equipped.

Two Administrations, who have no mobile gangs, have on the other hand fixed repair shops. These are the C.F.L., who have two small shops, and the N.S. who have ten shops in which men responsible for the small repairs to the movable bridges work (see No. 4.11). The N.S. shops are equipped with everything necessary for urgent repairs.

The replies to question 4.23 show that the shops in question do not come under any special regime. There is one exception, the M.A.V. who replied in the affirmative to this question, but did not give any details about this regime.

4.3) *What is the total number of men (inspectors, foremen and workmen) employed on the inspection and maintenance of bridges and viaducts?*

As regards the Administrations, who have bridge gangs, and no repair shops, and the Administrations who have repair shops the staff of which is included in the numbers of men in the gangs, the total number of men (as it appears from the replies) is given in one column of Plate 17. These data have already been examined (see No. 4.12).

As regards the replies received from Administrations who have bridge gangs and repair shops independent of these gangs, it may be noted :

— that the R.E.N.F.E. replied that the total number of men employed in inspecting and maintaining bridges is about 70. Obviously this only includes the men in the gangs and to this number must be added the 320 men employed in the shops as indicated under No. 4.21. The total number is therefore 390 men;

— the S.N.C.F. reports that the total number of men employed for the heavy repairs to bridges and viaducts is about 150. This number is somewhat higher than the overall total for the mobile gangs and the men employed in the small repair shops as given in the replies to Nos. 4.12 and 4.21.

According to the M.A.V. and the C.P. the number of men working on the bridges varies.

The Jugoslavian Railways replied that there is on the average one man per 500 m length of bridge (see No. 4.12).

4.4) *Apart from the special mobile gangs dealt with under 4.11) above, can other gangs be used for the inspection and maintenance of bridges (for example gangs of platelayers)? If so, what are their respective duties?*

On the Upper Congo to the Great African Lakes Railway, the native gangers under the orders of the district permanent way inspectors deal with the inspection and maintenance of bridges.

On the Viet-Nam Railways, the permanent way men deal with both the maintenance of the track and of masonry and concrete bridges.

Certain Administrations, who have no specialised gangs, mention however that men attached to the various departments or subdivisions of the railway, or even belonging to the permanent way gangs are responsible for small maintenance work (« Chemins de fer Economiques », Algerian Railways, C.F.L., Damas-Hama Railway).

The permanent way gangs are responsible for inspection and maintenance of bridges of the lines of the following Administrations : Lower Congo to Katanga, R. E. N. F. E., Finnish State Railways, S.N.C.F., « Chemins de fer Economiques », Djibouti to Addis Ababa Railway, M.A.V., F.S., C.F.F.

In general, the permanent way gangs are responsible for small maintenance work on bridges : keeping the approaches cut, sweeping and cleaning the decks, decking, guard-rails, and abutments; sometimes also for greasing the support equipment and tightening up the fastenings of the stringers and sleepers.

The permanent way gangs also sometimes supply additional men (labourers) for the mobile gangs working in their district, especially when laying and removing temporary bridges.

On the C.F.L. and C.P., it is only exceptionally that the permanent way gangs have anything to do with the inspection of bridges. In general, they merely have to report any damage requiring urgent steps to be taken and carry out the necessary supervision in case of danger.

Finally, the following Administrations gave a negative reply to question 4.4 : S.N.C.B., Matadi - Leo (O.T.R.A.C.O.), Cameroons Railways, N.S., Czechoslovakian and Jugoslavian Railways.

4.5) *What types of work do you have done by the railway staff and what work is usually contracted out to private industry in the case of :*

4.51) *metal bridges;*

4.52) *masonry and concrete bridges.*

If so, how is the work divided up?

Certain overseas Administrations themselves carry out all the maintenance work : Lower Congo to Katanga Railway, Matadi-Leo (O.T.R.A.C.O.), A.O.F. Railways, Djibouti to Addis Ababa Railway, Tunisian Railways.

PLATE 18. — **Résumé of the replies of Administrations to questions 4.21 and 4.22.**

Administration	*Shops*		*Equipment of the shops*		*Remarks*
	number	*staff*	*machines and tools*	*vehicles*	
R.E.N.F.E. (Spain) . .	4	320 (.)	The shops are fully equipped for all bridge repair work.	40 wagons	The total staff is 900 men of whom 320 (.) are specialised in bridge repair.
S.N.C.F. (France) . . .	1	4 men	Punch-shears, lathe, forge, drill, grinder, compressor, electric generating set.	none	This shop machines parts used by gangs in one of the S.N.C.F. regions.
Viet-Nam Railways . . .	?	3-4 workmen (in each shop)	Punch, drill, folding machine, reamer, milling machine, etc.	—	Men from the mobile gangs may be used to increase the numbers employed in these shops.
M.A.V. (Hungary) . .	One central shop 1 shop for each manag. district	various	The tools and equipment are based on experience to date.	—	The central shop is responsible for the more important maintenance work.
F.S. (Italy)	14	—	Drill, lathe, shears, grinder, saws, etc.	The vehicles belonging to the bridge gangs	The men are included in the bridge gangs. The maintenance of the gang's equipment and certain alterations and repairs are done in the shops.
C.F.L. (Luxemburg) . .	2	2 locksmiths 2 carpenters 2 masons 2 painters	nothing	—	—

PLATE 18. — **Résumé of the replies of Administrations to questions 4.21 and 4.22.** *(Continued.)*

Administration	*Shops*		*Equipment of the shops*		*Remarks*
	number	*staff*	*machines and tools*	*vehicles*	
N.S. (Holland)	10	164 men in all	Welding equipment, lathe, drill, small planer, sharpening machine, (shop equipment). Compressor, electric generating set, drills, pneumatic tools, jacks (for work out in the open).	trolleys bicycles	The men carrying out small repairs to the movable bridges work in these shops (see 4.11). Equipment is provided for emergency repairs.
C.P. (Portugal)	1	—	—	—	1 fixed repair shop.
C.F.F. (Switzerland)	3	—	Lathe, saws, drills, grinders, welding equipment, vices, shears, etc. A small overhead crane.	The vehicles of the bridge gangs	The employees are part of the bridge gangs. The work done in the shop covers the maintenance of the equipment and auxiliary bridges, as well as a certain amount of alterations and repairs.
Jugoslavian Railways	several	The staff varies according to the size of the shop	Drill, lathe, planer, shaping machine, grinder, press to rectify bridges, several compressors, welding equipment, electric crane, rivetting machine, complete locksmith's and blacksmith's equipment.	Several small Walter wagons. Several wagons. A lorry.	—

The Lower Congo to Katanga Railway reports however that new metal components are manufactured in Europe and sent out ready for assembly; and the Djibouti to Addis Ababa Railway states that the railway staff is strengthened if necessary by temporary staff.

Some Administrations, on the contrary, do not carry out any work for themselves (S.N.C.V., Cameroons Railways), whilst others only do their own work in certain special cases (S.N.C.B., D.S.B., N.S. — see No. 4.11).

The case of the M.A.V. and Czechoslovakian Railways must be considered separately. These Administrations carry out unimportant work themselves (the M.A.V. only work with concrete or reinforced concrete), but these Administrations have their own subsidiary company. The most important work is carried out by this undertaking or by other national undertakings attached to the different Ministries.

Eleven Administrations replied that they carry out certain work themselves with their own labour, and have other work done by contract by private firms.

The allocation of the work differs considerably however from one Administration to another.

The C.F.L. only carry out very small repairs themselves.

The Algerian Railways carry out small maintenance work to metal bridges themselves, and the Finnish Railways on the contrary themselves build and renew small reinforced concrete bridges.

The F.S. themselves only undertake maintenance (apart from repainting), small repairs, and in certain cases also average repairs to metal bridges.

It is the same on the C.F.F. and S.N.C.F.

However, those Regions of the S.N.C.F., which have specialised mobile gangs, use them for grouting with cement or plastic materials, and for repairing bridges by cement gun, when the expenditure involved does not exceed a few hundred thousand francs.

The « Chemins de fer Economiques » do their own small repairs to masonry bridges and repaint small metal bridges.

Finally, the R.E.N.F.E. and the Viet-Nam Railways only contract out large repairs, and the C.P. important work and work involving special equipment.

Obviously, the geographical situation is the chief factor in determining the advantage of carrying out certain work themselves.

Although some of the replies may seem to go against the conclusion that follows (see for example the reply from the Cameroons Railways) it appears that where the road network is adequate and consequently access to the bridges by road is not difficult, and there is no shortage of contractors in the district, carrying out the work oneself is not advantageous or only advantageous when the amount of work involved is very small.

It should be noted that the S.N.C.F., F.S., and C.F.F. have all the repainting of metal bridges done by contract.

4.61) *Do you keep a stock of the parts needed to carry out repairs in your depots, or do you buy such stores as and when required?*

The materials needed for the repair of metal bridges, carried out by the bridge gangs, is generally supplied from the stocks, stores or depots of the Administrations (see Plate 19).

The F.S. also have stocks of the materials required for repainting (see No. 4.62).

An examination of the replies summed up in the plate does not throw any light on the diversity of the principles according to which the Administrations build up their stores. Perhaps this is because of the different organisation of the departments dictated by causes that have nothing to do with the maintenance of bridges.

4.62) *When all or part of the maintenance work is done by contract, are the necessary stores supplied by the Administration or by the contractor?*

PLATE 19. — **Résumé of the replies of the Administrations to questions 4.5, 4.61 and 4.62.**

Administrations	*4.5. Work done by the Administration itself with its own employees*	*Work contracted out to private firms*	*4.61. Existing stocks*	*4.62 Supplying materials required for work contracted out*
S.N.C.B. (Belgium)	Small maintenance jobs on certain lines difficult of access by road, and repainting of metal bridges.	In general all maintenance and repair work.	No : whoever carries out the job buys directly the materials required for work done by the Administration.	The contractor normally supplies all the materials.
Belgian National Light Rlys Company	—	In general all maintenance and repair work.	—	The materials required are supplied by the contractor.
Lower Congo to Katanga Railways	In principle, all the work is done by the Administration itself.	New metal components are manufactured in Europe and sent out ready for assembly.	Stocks are only provided to cater for small repairs. In other cases the materials are purchased as required.	—
Matadi-Leo Railway	Normally maintenance work is carried out by the railway staff.	—	The materials required for one year's estimated work are stocked.	Does not apply.
D.S.B. (Denmark)	—	In general, all maintenance, repair and reinforcement work.	The D.S.B. hold certain stocks of steel.	The D.S.B. themselves purchase the steel, cement, isolating materials and paint.
R.E.N.F.E. (Spain)	—	General rebuilding and large repairs.	Stocks are usually available in the stores.	May be provided by either party according to the materials in question.
Finnish State Railways	The railway staff normally build and renew small reinforced concrete bridges.	Larger concrete bridges and all metal bridges.	The materials are purchased as required.	The materials needed are supplied by the contractor.

PLATE 19. — **Résumé of the replies of the Administrations to questions 4.5, 4.61 and 4.62** *(continued)*.

Administration	*4.5. Work done by the Administration itself with its own employees*	*Work contracted out to private firms*	*4.61. Existing stocks*	*4.62 Supplying materials required for work contracted out*
S.N.C.F. (France)	Running repairs and a proportion of the average repairs on metal bridges, after the possibilities and cost have been compared with those of the contractors, according to the geographical situation of the bridges. Grouting with cement or plastic materials, repairing bridges by cement-gun in regions with specialist mobile gangs, when the expense involved does not exceed a few hundred thousand francs.	Construction of new metal bridges, big reinforcement jobs, and repainting. Part of the average sized repairs to metal bridges after inspection. Masonry or concrete work is not entrusted to the gangs. In general all work which involve keeping the mobile gangs too long at one site.	The materials required for the repairs to metal bridges (flats, sections, rivets, bolts) lead and antimony needed for wedging the supports are stocked. Rubber, materials for grouting and the materials needed for maintenance of concrete bridges are purchased as required.	The materials needed are supplied in principle by the contractor. When it is a question of painting, the paint must be purchased from an agreed manufacturer, agreed by the S.N.C.F., who has in his factory a supply of paint which the S.N.C.F. has previously passed as satisfactory.
Chemins de fer Economiques (France)	Small repairs to the face, repointing, repairs to the masonry of wing and flank walls, repairs to copings, repainting small metal bridges, replacing lead bearing plates by rubber plates, repairs to handrails and decking.	Important work, such as rebuilding the masonry and repainting large bridges.	The materials are purchased as required.	The materials needed are supplied by the contractor. However, paint is sometimes purchased directly by the Company.
Algerian Railways	Small maintenance jobs on metal bridges.	All work of any importance.	The materials are purchased as required.	The paint needed for the maintenance of metal bridges is purchased by the Administrations. It is supplied to the contractor as needed.
Cameroons Railways	—	All maintenance and reinforcement work.	—	All parts and materials supplied by the contractor.

Administrations	*4.5. Work done by the Administration itself with its own employees*	*Work contracted out to private firms*	*4.61. Existing stocks*	*4.62 Supplying materials required for work contracted out*
French West African Railways	All maintenance work.	—	Small stocks are kept.	Does not apply.
Djibouti to Addis Ababa Railway	In general, all the work is carried out by the Administration by its own staff, additional labour being engaged temporarily if necessary.	—	Materials for urgent repairs are stocked. The other materials are ordered according to the annual maintenance programme	In principle no maintenance work is done by contract.
Viet-Nam Railways	All maintenance work and small repairs.	Building or large repairs.	Most of the materials are supplied by the Stores Department. However, in the case of certain materials (timber, lime, cement) these are ordered from suppliers for delivery before the work starts.	The materials required are supplied by the contractor. However the contractor may ask for delivery against payment of certain materials that are difficult to procure in the open market of which the railway has some stocks.
M.A.V. (Hungary)	Work of lesser importance in concrete and reinforced concrete.	Metal work as well as concrete and reinforced concrete work of greater importance is done by State undertakings or by the Bridge Construction Department.	Stock of materials to meet requirements for several months.	—
F.S. (Italy)	Maintenance work and small jobs to metal bridges. Exceptionally, repairs of average importance to metal bridges.	Construction of new metal bridges, reinforcements and repairs of large and average importance. Repainting. The maintenance, repair and construction of masonry or concrete bridges.	Stock of materials required for the work done by the bridge gangs. Paint.	The paint needed for repainting metal bridges are supplied to the contractor by the Administration.
C.F.L. (Luxemburg)	Small maintenance jobs.	Important work.	The materials needed for the small jobs are stocked in the Administration's stores.	All the materials are supplied by the contractor.

PLATE 19. — **Résumé of the replies of the Administrations to questions 4.5, 4.61 and 4.62** *(continued)*.

Administrations	*4.5. Work done by the Administration itself with its own employees*	*Work contracted out to private firms*	*4.61. Existing stocks*	*4.62 Supplying materials required for work contracted out*
N.S. (Netherlands)	Only small repairs to movable bridges.	In general, all maintenance and repair work.	No large stocks are held.	The materials are supplied by the contractor as approved by the N.S.
C.P. (Portugal)	—	Only the building of large bridges or bridges requiring special equipment.	The C.P. hold stocks of materials for repairs.	In general, the materials are supplied by the contractor.
C.F.F. (Switzerland)	Metal bridges : Inspection, replacing rivets, repairs and small alterations and current maintenance. The bridge gangs are if necessary strengthened by outside labour. Concrete and masonry bridges : maintenance of the handrails, metal protective plates, supports. Supplying and erecting auxiliary bridges needed for carrying out work is the job of the Administration.	Complete repainting of metal bridges. In general repairs to concrete and masonry bridges.	Stock of rivets, electrodes and paint for the bridge gangs. A certain stock of iron sections, generally second hand.	The C.F.F. supply the paint. Other materials are supplied by the contractor.
Damas-Hama Railways	Normal maintenance.	Large repairs.	—	The contractor is responsible for supplying steel sections.
Czechoslovakian Railways	Work of lesser importance.	Big jobs such as rebuilding bridges are carried out by the national building and assembly undertakings of the Ministry of Heavy Industry and by contract for the Ministry of Transport.	The Ministry of Transport has a special Stores Department. The branches attached to the regions are supplied with materials according to the annual programme prepared by the technical permanent way department. They also hold adequate stocks to meet unexpected demands.	The national undertakings procure the materials according to plan.
Tunisian	Maintenance work	—	Materials are purchased	—

In general, the contractor supplies all the materials required to carry out the work with which he has been entrusted (see Plate 19).

However, the Algerian Railways, the F.S. and the C.F.F. supply the contractor with the paint needed to repaint metal bridges. These paints are sometimes also bought directly by the « Chemins de fer Economiques ».

The S.N.C.F. stipulate that the paint shall be bought by the contractor from an agreed supplier, who has in his factory a stock of paint previously passed by the S.N.C.F.

The D.S.B. purchase directly and supply the contractor with the paint, and also the steel, cement and isolating materials.

4.7) *What types of maintenance to metal bridges do you carry out on site and to what extent are small bridges moved if necessary to the shops of the Administration or contractor?*

All the Administrations are agreed on this point.

Maintenance and repair work is generally done on site, when it can be carried out while the trains are running and during periods when the traffic is stopped.

The parts required are prepared in the shops if possible.

Some Administrations only replied to this part of question 4.7) concerning the possible transport of small bridges to the Administration's or contractor's repair shops.

The S.N.C.B. replied that this was exceptional.

According to the D.S.B. repairs to metal bridges are only carried out in the contractors shops when it is question of very extensive repairs or reinforcements.

The S.N.C.F. says that small bridges are sometimes taken to the contractor's depot (very rare case) or to a nearby station, when the amount of work justifies this and transport is not too costly and it does not involve a lot of dismantling of parts to begin with.

The « Chemins de fer Economiques » gave a similar reply.

The French West African Railways report that small bridges are repaired at the railway repair shops only when they have to be strengthened.

According to the Djibouti to Addis Ababa Railway, if a bridge is to be dismantled and brought into the shops, this means that the main beams have to be rectified, or else some very important modification made in its design, which is very rare and nearly always the result of an accident.

The Czechoslovakian Railways report that in certain cases a temporary structure is used and the bridge repaired by the side of the track.

In other cases a few bridges less than 10 m long have been repaired and strengthened effectively in the auxiliary repair shops of the Administration.

The F.S. and C.F.F. replied that in certain cases they have had to transport small metal bridges into the shops, when it was worth the trouble and the operation was relatively easy.

These Administrations point out however that such a procedure is not the usual one on their railway and when they have to make fairly important repairs or reinforcements to small metal bridges, they prefer to replace them with reinforced concrete decking.

The C.F.L. on the contrary replied that, except for repainting, which is always carried out on site, metal bridges less than 3.5 m long are taken into and repaired in a privately owned metal construction shop.

4.8) *Is the work of the mobile gangs in the district to which they are attached carried out according to a predetermined programme, or as inspection shows that work is necessary?*

— The Algerian Railways replied that the regional gangs only go out of their own region in case of urgency and at the request of local officials.

Administrations	*Inspection and regular quarterly or weekly inspections*	*Annual inspections*
S.N.C.B. (Belgium) . .		
Belgian National Light Railways (Belgium) . .		
Lower Congo to Katanga Railways		*By the district permanent way ins with or without a topographer :* me ment of the versines and general i tion of bridges.
Upper Congo to Great African Lakes Railways .	The bridges are very regularly inspected by the district permanent way inspectors.	
Matadi-Leo Railway . .		*By the district permanent way inspe* as detailed a visual inspection as po
D.S.B. (Denmark) . . .		Inspection by local inspection responsible for the maintenance permanent way.
R.E.N.F.E. (Spain) . .		Cursory inspections.
Finnish State Railways . .		By the districts.
S.N.C.F. (France) . . .		Annual inspection of certain bridge have to be specially watched.
Chemins de fer Economiques (France)		Annual inspection of all bridges.
Algerian Railways. . . .	All bridges are given a cursory inspection by the gang foreman and district permanent way inspector during their tours of inspection.	More thorough inspections carried c the district permanent way insp
Cameroons Railways . .	Cursory inspections half-yearly.	
French West African Railways	Cursory inspections quarterly by the district permanent way inspector.	Detailed inspection.

ations to question 4.9.

Other inspections	*Period*	*Remarks*
he engineer responsible for the bridges on the l services assisted by building inspectors : metal railway bridges; masonry bridges of more than 2 m span and overbridges; *technical inspectors and permanent way ectors :* bridges of less than 2 m span; bridges of more than 2 m span (*).	 2 years 4 years 2 years 4 years (*)	(*) Cursory inspection.
ion of bridges.	5 years	
		No distinction between cursory and thorough inspections.
ularly thorough inspection made by local ion gangs *(main inspections).*	5 years	When it is considered advisable, especially in the case of the main inspections, the engineers of the Bridges Department are present at these inspections
al inspection carried out by the Central gement.	7 years	
ed inspection of metal and reinforced concrete s carried out by the Head of the district res- le for writing the report. This inspection the levels of the supports and checking the nent deflections in the case of bridges of	5 years	The inspection of the bridges is not the responsibility of the maintenance gangs. The permanent way inspector can ask for the assistance of a bridge inspector when inspecting certain bridges. In the case of some bridges, the inspection is made by the bridge inspector at the same time as the permanent way inspector.
ed inspection of reinforced concrete bridges etal bridges including levelling the supports easuring the deflections on bridges of more 15 m span.	5 years	
led inspection made by the district permanent nspectors . This inspection includes the level- f bridges the span of which exceeds 10 m.	5 years	The inspectors of the Office in charge of bridges make additional inspections and carry out experimental measurements of deformations and stresses under overloads.
ctions combined with checking the deflections.	5 years	
detailed inspection of metal bridges, checking ermanent deflection, and in the case of con- us beams, checking the levels of the supports.	4 years	The results of the annual and four-yearly inspections are entered in the records for each bridge.

Administrations	*Inspection and regular quarterly or weekly inspections*	*Annual inspections*
Djibouti to Addis Ababa Railway		A detailed inspection of every br made by the district permanen inspector.
Viet-Nam Railways . . .		The *gang foreman* inspects all brid less than 2 m span. The *district permanent way ins* accompanied or not by the gang fo inspects all bridges with a span of over, except those metal bridges will be the subject of a four-year pection that year or the next.
M.A.V. (Hungary) . . .	Quarterly inspection of each detail of bridges carried out by the district permanent way inspector.	
F.S. (Italy)	Continuous supervision by the platelayers.	Inspection of all bridges made b district permanent way inspector.
C.F.L. (Luxemburg) . .		Cursory inspections.
N.S. (Holland).	Thorough inspection every six months of movable bridges. Cursory inspections.	Thorough inspection.
C.P. Portugal)		Inspection of old bridges.
C.F.F. (Switzerland) . .	The district permanent way inspectors during their tours of inspection also have to inspect the bridges and report any defects.	
Damas-Hama Railways .	Inspection by the district permanent way inspectors.	Annual inspections.
Czechoslovakian Ministry of Transport		Inspections by the district permaner inspector.
Tunisian Railways . . .		Inspection made by the district perm way inspector.

Other inspections	*Period*	*Remarks*
...orough inspections, with tests of the load, if ...ry, of metal bridges carried out by an en- ...appointed by the Chief Permanent way En- ...in the presence of the State Control Engineer.	5 years	The result of the annual inspections is entered in the Bridge Register and communicated to the V. B. Central Department. The four-yearly inspections are the subject of a report.
...tions of metal bridges carried out by the ...visional Inspectors accompanied by the dis- ...spectors for metal bridges.	4 yea rs	The annual and four-yearly inspections are the subject of reports. The annual inspections must be completed by the end of May of each year. The reports made at the end of the four-yearly inspections must be sent in not later than the end of March of each year to the Higher Authorities, so that orders for materials can be given in time.
...ic thorough inspection carried out by the ... gangs.	8 years	
...ed inspection of metal bridges made by the ...al engineer responsible for metal bridges ac- ...nied by the district permanent way inspector. ...spection is carried out with the assistance of ...idge gangs.	6 years	The annual and six-yearly inspections are the subject of reports.
...ugh inspection of metal bridges.	5 years	
		The results of the six-monthly and annual inspections are given in a report.
...lic inspections of new bridges at different ...als as predetermined in each case.		The normal inspection of bridges is the responsibility of the inspection and maintenance gangs; more thorough or special inspections are accompanied by inspectors of the respective departments.
...ugh examination carried out by the bridge ... (in the case of bridge known to be in good ...tion, the gangs make a thorough inspection ... ten years, with a cursory inspection during ...terval).	5 years	
...dic inspections.	5 years	
...al inspection carried out by the central brid- ...partment of the region.	6 years	In their reply to question 4.11 the C.S.D. stated that the regional gangs periodically inspected railway bridges of more than 10 m span, and the local gangs the others. The C.S.D. did not state at what periods such inspections were carried out.
...ction carried out by a State Control Engineer ...panied by the district permanent way inspec- ...oncerned.	5 years	

PLATE 21. — **Résumé of the replie**

Administrations	*Amortisation period*	*Estimated life when designing the bridges*		
		metal	*reinforced concrete*	*masonr*
S.N.C.B. (Belgium)	—	60 years	75 years minimum	75 years minimu
Lower Congo to Katanga Raylways	50 years	—	—	—
Matadi-Leo Railway (O.T.R.A.C.O.)	75 years (1) 90 years (2)	50 years	unlimited	unlimite
D.S.B. (Denmark).	400 years	—	—	—
R.E.N.F.E. (Spain)	—	100 years	—	indefini
Finnish State Railways . . .	—	—	—	—
S.N.C.F. (France)	—	—	—	—
Chemins de fer Economiques (France)	—	—	—	—
Algerian Railways	—	—	—	—
Cameroons Railways	60 years	—	—	—

ations to questions 1.11 and 1.12.

Actual life of the bridge			*Age of the oldest bridges on the system*			*Remarks*
l	*reinforced concrete*	*masonry*	*metal*	*reinforced concrete*	*masonry*	
ars	—	much more than 75 years	—		more than 100 years	—
	—	—	45 to 50 years			These bridges are still in very good condition.
	—	—	26 to 35 years			(1) Metal bridges. (2) Concrete and masonry bridges. All these bridges are in good condition.
	—	—	—			It is not possible to give the real life of the different types of bridges.
ears	—	indefinite	—			—
-	—	—	70 years	—	—	—
ears to rs (2)	100 years (1) 30 to 50 years (2)	150 years	—			(1) From experience which in fact does not cover more than 50 years. (2) Metal and reinforced concrete bridges exposed to smoke.
—	—	—	85 years			—
—	—	—	—			Thanks to proper maintenance, the bridges will last many more years.
—	—	—	—			—

PLATE 21. — **Résumé of the replies**

Administrations	*Amortisation period*	*Estimated life when designing the bridges*		
		metal	*reinforced concrete*	*masonr*
French West African Railways	—	50 years	unable to estimate	
Djibouti to Addis Ababa Railway	—	undetermined		
Viet-Nam Railways	—	70 years	—	100 yea
M.A.V. (Hungary)	70 years	—	—	—
F.S. (Italy)	—	80 years	no estimate is made	
C.F.L. (Luxemburg)	—	50 years	75 years	150 year
N.S. (Netherlands)	100 years	—	—	—
C.P. (Portugal)	—	50 years	no well-defined opinion	unlimite
C.F.F. (Switzerland)	66 2/3 years	80 years (1)	80 years (1)	100 years
Czechoslovakian Railways . .	—	80 years	200 years (arches) 120 years (beams) 100 years (mixed bridges)	200 year (in granit or very go concrete 150 year (in hard s or concre 100 year (in brick or soft sto
Jugoslavian Railways	—	50 years	80 years	80 year

rations to questions 1.11 and 1.12 *(continued)*.

Actual life of the bridge			*Age of the oldest bridges on the system*			*Remarks*
al	*reinforced concrete*	*masonry*	*metal*	*reinforced concrete*	*masonry*	
	—	—	—	—	50 to 70 years	—
undetermined			—			—
	—	—	40 to 70 years			—
ears age)	—	70 (in brick) 100 (in stone uncracked by frost)	more than 100 years			—
ears age)	—	—	90 years	57 years	150 years	—
real life may be greater than the tate.			—			—
0 100 ars	—	—	—			—
—	—	—	99 years	61 years	104 years	—
—	—	—	—			(1) Life taken in account when calculating the compensation to be paid in the case of bridges built by some other party.
actual life is generally the same as theoretical.			—			—
theoretical life is generally reached even exceeded.						

— The work of the mobile gangs is based on what it is found needed on the Lower Congo Katanga and C.F.L. Railways.

— The C.F.L., however, as we saw under Nos. 4.11 and 4.4 have no gangs, but only workmen.

The Matadi-Leo and the « Chemins de fer Economiques » replied that the work of the gangs is based on a programme drawn up in advance, but they do not explain how this programme is prepared.

The R.E.N.F.E. replied that the working programme is prepared in advance, according to circumstances.

The Czechoslovakian Railways stated that the working plan is prepared « according to the experience previously acquired ».

The plan of work is drawn up according to a cycle by the M.A.V. (8 year period) and the C.F.F. (5 year period).

Finally, the working programme of the mobile gangs is prepared in advance according to the findings obtained during periodic inspections (see No. 4.9) on the S.N.C.F., the Djibouti to Addis Ababa Railway, the Viet-Nam, F.S. and C.P. Railways.

The F.S. and C.P. add that the working plan prepared in advance has to be adjusted to meet actual contingencies.

4.9) *Apart from the inspections made by these gangs, do you carry out periodic inspections of bridges? If so, at what intervals? Do you make a distinction between a summary inspection and a thorough examination?*

Plate 20 sums up the data concerning the rules that the different Administrations follow as regards the inspection of bridges. These data are taken from the replies to question 4.9 and in certain cases replies to previous questions.

It should be pointed out first of all that in general the inspection of bridges is not the business of the bridge gangs, but the responsibility of the District Permanent Way Inspectors, who during their tours of inspection have to examine the bridges as well as report anything that is wrong, and in addition on most railways, they are responsible for making a detailed inspection of the bridges each year.

Many Administrations require annual inspections to be carried out and more thorough inspections at longer intervals. These latter are sometimes only made in the case of reinforced concrete bridges and metal bridges, or even only in the case of metal bridges.

These long term inspections are generally carried out by specialist engineers in conjunction with the permanent way inspectors.

The data given in Plate 20 refers only to ordinary inspections.

Certain Administrations in their replies took into consideration the special inspections made to temporary bridges, bridges that are being kept under observation, or bridges which may have suffered damage due to exceptional causes.

Other Administrations also mentioned occasional inspections or inspections carried out in special cases (for example when considering the possibility of allowing heavier loads over the bridge).

* * *

GENERAL CONSIDERATIONS.

1.11) *When designing a new bridge, what estimates do you make for each type of structure, as regards the length of life in service that can reasonably be expected, taking into account all the factors which normally affect this life?*

1.12) *Since the above life must be considered as the ideal, what is the actual length of life of bridges subdivided into types as above?*

Obviously untoward incidents are not to be taken into acount.

In their replies to question 1.11 (see Plate 21) certain Administrations give estimates concerning the expected life of bridges which, even if this is not expli-

citely stated, are obviously merely made in order to introduce an amortisation coefficient into their budgets. In general, these completely conventional estimates make no distinction between different types of structures. Thus the Lower Congo to Katanga Railway gives an expected life of 50 years for all its bridges, the Cameroons Railways, 40 years, the C.F.F. provide a sinking fund rate of 1.5 % for all categories, i.e. from the accountancy point of view, all bridges, without distinction, are amortised in 66 $^2/_3$ years, the M.A.V. give all bridges a life of 70 years, the Matadi-Leo Railway, 75 years for metal bridges and 90 years for masonry bridges; the N.S. 100 years for all masonry bridges, and finally the D.S.B. includes bridges in the superstructure as a whole for which the amortisation period is 400 years.

Apart from these conventional estimates, it should be noted in the first place that according to certain Administrations when studying a new bridge, the choice of structure is in no way influenced by the presumed life of the different types.

This is sometimes due to local conditions. The Finnish State Railways for example state that on account of the flat nature of the country, it is rarely possible to choose any other type than a metal bridge for long spans, and reinforced concrete for smaller spans.

The Algerian Railways, on the contrary affirm explicitely that the life of the bridge does not come into their estimates, and the S.N.C.F. holds that in selecting the type of bridge, when the studies are first begun, the idea of its expected life generally only comes into the picture implicitely and in the last resort, other more important factors (thickness of the deck, facility of obtaining materials and building the bridge, time taken to build it) have to be considered first of all.

It should be pointed out here that the Administrations who according to their replies take into account when studying a new bridge the presumed life of the bridge, do not say in what way this is taken into account.

In effect, if it is merely calculated in economic terms based on financial mathematical formulae, one necessarily comes to the conclusion that the presumed life is of little importance. This conclusion is obvious from the following table in which for different value of interest, the capital sum has been calculated which, by using the interest, would make it possible to renew every year a bridge costing P.

Number of years	i = 0.035	i = 0.04	i = 0.05	i = 0.06
x =				
50	0.218 P	0.164 P	0.096 P	0.058 P
80	0.068 P	0.045 P	0.021 P	0.010 P
100	0.033 P	0.020 P	0.008 P	0.003 P

But it must be pointed out that in general the shorter life goes hand in hand with costlier maintenance.

Finally, it would appear that an economic comparison of the possible solutions should be made adding to the cost of the bridges the sums required to assure their regular maintenance and renewal in the future.

A calculation of this type is made by the C.F.F. in the particular case of over and underbridges built by other interests.

The object of such a calculation is to establish the indemnity to be asked for when the C.F.F. take over the cost of maintaining and renewing such bridges.

The C.F.F. allow a life of 80 years for metal reinforced concrete and prestressed concrete bridges, and 100 years for masonry bridges. They have also estimated the following rates of maintenance as a percentage of the value: 0.8 % for metal or prestressed concrete parts, 0.6 % for reinforced concrete parts and 0.5 % for masonry parts. Finally, for the above three classes the maintenance cycles are taken as 20, 25 and 30 years respectively.

The C.F.F. have taken the rate of interest as 3 ½ %. Taking into account the above factors the following sums were finally arrived at as a percentage of the cost of the bridge:

Classes	Maintenance	Amortization	Total
Steel parts (including paint), parts in pretressed concrete	16.1 %	6.8 %	22.9 %
Parts in reinforced concrete, beams incased in concrete	11.0 %	6.8 %	17.8 %
Parts in concrete not reinforced and in masonry, tunnels	8.3 %	3.3 %	11.6 %

According to these results taking P_a, P_b, and P_m respectively as the cost of the three bridges in steel, reinforced concrete and masonry, it should be concluded that these three bridges are equal from the economic point of view when:

$$P_b = \frac{1.229}{1.178} P_a = 1.043 \ P_a$$

and $$P_m = \frac{1.229}{1.116} P_a = 1.101 \ P_a.$$

It will be noted that there is no great difference between P_a, P_b, and P_m.

It should be added that the rate of interest at 3 ½ % is certainly lower than it would be in most European countries.

With a higher rate of interest, the rates for maintenance and renewal are reduced and a reduction is obtained in the values of P_b and P_m compared with P_a.

As a result of the above considerations, and lacking further information from the Administrations who replied to question 1.11 concerning the estimated life of each type of structure, the Reporter thinks that even these Administrations follow the same lines as those reported by the S.N.C.F. in practice.

From the replies of these Administrations we get:

— the estimated life of metal bridges is:

50 years (Matadi - Leo Ry., French West African Rys., C.F.L., C.P., Jugoslavian Rys.);
60 years S.N.C.B.;
70 years Viet-Nam Rys.;
80 years F.S., C.F.F., Czechoslovakian Rys.;
100 years R.E.N.F.E.;

— the estimated life of reinforced concrete bridges is:

75 years S.N.C.B., C.F.L.;
80 years C.F.F., Jugoslavian Rys.

The Czechoslovakian Railways estimate :

100 years for mixed bridges with reinforced concrete decking and steel beams;
120 years for reinforced concrete beams;
200 years for reinforced concrete arches.

The Matadi-Leo Railway, estimates an unlimited life for reinforced concrete bridges, the C.P. have no definite opinion, the French West African Railways and the F.S. state that they do not make any estimates.

The estimates concerning the life of masonry bridges are :

75 years minimum S.N.C.B.;
80 years Jugoslavian Rys.;
100 years Viet-Nam Rys.; C.F.F., Czechoslovakian Rys., (with arches made of bricks or soft stone);
150 years C.F.L., Czechoslovakian Rys., (for arches made of hard stone or concrete);
200 years Czechoslovakian Rys., (for arches made of granite or very high quality concrete).
Unlimited expectation of life : Matadi - Leo Ry., R.E.N.F.E., C.P.

The French West African Railways and F.S. Railways replied that they do not make any estimates. These Administrations perhaps meant by this reply that they expect an unlimited life.

* * *

Many Administrations report that it is very difficult to give any answer to question 1.12 concerning the actual life of each type of bridge.

The D.S.B., F.S. and C.F.F. gave the factors which in their opinion influence the life of bridges but also stressed the fact that the influence of such factors is very variable and it is consequently very difficult to establish what is the average life of a bridge.

Formerly, many metal bridges, even those built not long before, had to be replaced because of the increase in the loads; the tipical trains of 40 or 50 years ago show a large margin compared with the real loads and consequently it appears that in the case of metal bridges built during this latter period it will not become necessary to replace them on account of an increase in the loads.

The following Administrations stated that the real life of metal bridges corresponds to the estimated life : S.N.C.B. (60 years) F.S. and Czechoslovakian Railways (80 years).

Even other Administrations who did not answer this question 1.11 (S.N.C.F.) or who gave a conventional reply (M.A.V.) report an average life of 80 years for metal bridges.

According to the N.S. this period varies between 70 and 100 years.

Only the R.E.N.F.E. which in studying a new metal bridge estimate its life as 100 years, state that the real life is shorter than that estimated.

It would appear that, taking the replies received as a basis, it can be concluded that the real life of a metal bridge is about 80 years.

At this point, however, we must ask ourselves if this conclusion at which we have arrived after examining considerations relating to old bridges, nearly all made of puddled iron, is valid for existing bridges, built more recently of steel, with different and more careful working methods and different constructional arrangements.

In the opinion of the reporter the answer should be in the negative. In reality, our experience of steel bridges is insufficient to lead to final conclusions.

Taking into account the conclusions concerning the life of iron bridges and the fact that most steel bridges built in the last 50 years are still in good order generally, the reporter thinks that in the case of steel bridges a life of 80 years constitutes a minimum which, failing exceptional events and particularly difficult sites, should be reached and even considerably exceeded, provided the bridge is suitably maintained.

— As regards reinforced concrete bridges, our experience is still smaller. We

cannot even speak of their average life, as apart from the fact that certain reinforced concrete bridges dating from the time this method of construction was first introduced are still in service and expected to last for many years yet, certain more recent bridges have already had to be replaced owing to defects in their design or construction.

In the same way, it is impossible to speak of the average life of masonry bridges. On most of the European main line railways there are still many bridges dating from the time the railway was built.

In certain cases, part of a road bridge already in existence was used for the railway and such bridges are still carrying the most modern locomotives without any restrictions (F.S. : Turin-Milan line — bridge over the Tessin).

It seems therefore justifiable to admit that, apart from accidents, the life of a well designed masonry bridge, built with good quality materials and regularly maintained, is practically unlimited.

As regards metal bridges and reinforced concrete bridges, it should be noted that according to the S.N.C.F. if bridges are exposed to smoke, the average life is considerably reduced as a result (40 to 50 years instead of 80 in the case of metal bridges and 30 to 50 years instead of 100 in the case of reinforced concrete bridges).

1.21) *In your budget under what headings do you include the maintenance and renewal of bridges?*

Is the amount allocated for this purpose based on the value of the bridges when new, on their present value or on their replacement cost? What is the total percentage compared with one or other of the above values? If you make use of other principles in your estimates, please state what these are.

a) *Maintenance costs.*

Most of the Administrations (D.S.B., Finnish Railways, « Chemins de fer Economiques », Algerian Railways, Djibouti to Addis Ababa Railway, Viet-Nam Railways, M.A.V., F.S., C.F.L., C.F.F.) reply that the funds set aside for maintenance are in principle a function of the condition of the bridges, as ascertained during inspection, rather than of their overall value.

The R.E.N.F.E., French West African Railways and C.P. replied that the budget provisions for maintenance are based on the experience acquired and on the costs in previous years.

The S.N.C.F., in 1948, when conditions had more or less returned to normal, estimated the amounts under the different headings of the pre-war operating budget by increasing appreciably, in the total budget, the amount formerly devoted to bridges.

A figure was obtained compatible with the budget as a whole and the allocation per region was done on a weight basis.

According to the S.N.C.F., it is not possible to state that the amount devoted to maintenance is based on the replacement value; it is rather a function of the present value.

Certain Administrations fix the budget items on the basis of the maintenance cycle. Thus the Matadi-Leo Railway replied that they provide for complete maintenance every 5 years, and the Cameroons Railways stated that the annual maintenance allowance in the budget is based on complete repainting every 8 years.

Finally, there are four Administrations who fix the amounts for maintenance in relation to the overall value of the bridges, but different principles are used as the basis for establishing this value (S.N.C.B., Czechoslovakian Railways, N.S., Jugoslavian Railways).

b) *Renewal costs.*

According to the S.N.C.F. the rebuilding of bridges only takes place as a result of exceptional circumstances (floods, accidents, etc.) and in general it is question rather of heavy repairs.

PLATE 22. — **Administrations who establish their budget appraisals for the maintenance and renewal of bridges based on the value of the bridges when new, or on the present value, or on their replacement value.**

Adminis-trations	*Metal bridges : percentage for :*			*Reinforced concrete bridges : percentage for :*			*Masonry bridges : percentage for :*			*Remarks*
	main-tenance	*renewal*	*total*	*main-tenance*	*renewal*	*total*	*main-tenance*	*renewal*	*total*	
S.N.C.B. (Belgium)	0.5 %	1.6 %	2.1 %	0.25 %	0.665 %	0.915 %	0.25 %	0.665 %	0.915 %	of the value of the bridge when new, calculated at present prices.
M.A.V. (Hungary)	—	1.5 %	—	—	1.5 %	—	—	1.5 %	—	of the total value of the bridges (real value of old bridges and cost of construction of bridges built since the second world war).
N.S. (Netherl.)	1.5 %	1 %	2.5 %	1.5 %	1 %	2.5 %	1.5 %	1 %	2.5 %	of the replacement value.
Czecho-slovakian Railways	0.75 %	1.25 %	2.00 %	0.47 %	0.83 %	1.3 %	0.5 %	1 %	1.5 %	of the present value of replacement.
				(beams in reinforced and prestressed concrete)			(bridges in bricks or soft stone)			
				0.3 %	0.5 %	0.8 %	0.43 %	0.67 %	1.1 %	
				(bridges and arches working essentially in compression)			(bridges of hard stone or present day quality concrete)			
				0.6 %	1 %	1.6 %	0.3 %	0.5 %	0.8 %	
				(mixed bridges)			(bridges in granite or very good concrete)			
Yougo-slavian Railways	0.7 %	2 %	2.7 %	0.2 %	1.2 %	1.4 %	0.2 %	1.2 %	1.4 %	of the value of the bridges when new.

PLATE 23. — **Résumé of the replies of the Administrations to Question 1.22.**

Administrations	*Actual expenditure during the last five years*		*Difference (plus or minus) compared with estimates*		*Remarks*
	on maintenance	*on renewals*	*on maintenance*	*on renewals*	
S.N.C.B. (Belgium)	92 613 000 B. fr.	276 885 000 B. fr.	— 1 285 000 B. fr.	— 91 814 000 (1) B.fr.	(1) From the percentages given in the reply to *1.21*, the cost of renewal is estimated at 40 000 000 Belgian fr., the maintenance cost 21 700 000 Belgian fr. a year.
Matadi-Leo Railway O.T.R.A.C.O.	2 465 592 B. fr. (2)		+ 210 592 (2)		(2) The reply covers 4 years : the actual expenditure each year shows remarkable variations.
D.S.B. (Denmark)	15 000 000 DKr				
R.E.N.F.E. (Spain)	21 503 824.82 Ptas	11 767 640.90 Ptas	— 1 336 000 Ptas		
Finnish State Railways	251 000 000 Fin. marks	652 000 000 Fin. marks			The funds allocated were lower than the corresponding estimates.
S.N.C.F. (France)	2 470 000 000 Fr.fr.	8 698 000 000 (3) Fr.fr.	The gap between expenditure each year and the estimates did not exceed 10 % (generally below this, except in 1956).		Renewals and heavy repairs.
Djibouti to Addis Ababa Railway	16 100 000 fr. d.	13 400 000 fr. d.			
Viet-Nam Railways	3 500 000 piastres VN yearly from 1955		The corresponding estimates are higher (about 25 %).		This state of affairs is the result of financial difficulties inherent in a postwar economy.
M.A.V. (Hungary)	19 000 000 florins during the last 3 years	62 000 000 florins		+ ?	More than 1.5 % of the total value (see *1.21*) has been spent in renewing bridges in the interest of better maintenance and increasing the capacity of lines.

PLATE 23. — **Résumé of the replies of the Administrations to Question 1.22** *(continued)*.

Administrations	*Actual expenditure during the last five years*		*Difference (plus or minus) compared with estimates*		*Remarks*
	on maintenance	*on renewals*	*on maintenance*	*on renewals*	
F.S. (Italy)	3 000 000 000 It. liras	8 250 000 000 It. liras			The total expenditure is only about 3.1 % of the value of the bridges (0.62 % during each year). The amounts allocated under the different budget headings are insufficient for regular maintenance of the bridges.
C.F.L. (Luxemburg)	4 600 000	6 800 000	The differences are insignificant.		
N.S. Netherlands	7 500 000 Dutch fl.	20 000 000 (4) Dutch fl.			(4) The consequences of the war have not yet been wiped out.
C.P. (Portugal)	10 000 contos		— 3 000 contos		The difference (lower expenditure) is the result of delays in obtaining materials.
C.F.F. (Switzerland)	9 031 000 Sw. fr.	4 580 000 Sw. fr.			Average annual maintenance costs: 0.5 % of the present value of the bridges.
Czechoslovakian Railways	30 000 000 Kcs annually	27 000 000 Kcs for general repairs 45 000 000 Kcs for reconstruction.	In general — 5 % to — 10 %.		
Jugoslavian Railways	6 178 000 000 dinars		+ 102 000 000 dinars		

Many Administrations replied that the amount set aside in the budget for the renewal of bridges is based on requirements and according to the railway modernisation programme, taking the current financial position into account (D.S.B., R.E.N.F.E., Finnish Railways, French West African Railways, Viet-Nam Railways, F.S., C.F.L., C.P. and C.F.F.).

It must be stated here that certain Administrations have no renewal funds, whilst other Administrations who are not carrying out any renewals now nevertheless have set up such a fund, from the annual sinking fund charges (Lower Congo-Katanga Railways, Matadi-Leo Railway, Cameroons Railways).

Finally, the S.N.C.B., the N.S., and Czechoslovakian and Jugoslavian Railways, which as we have already seen fix the budgetary amounts for maintenance according to the overall value of the bridges, do the same for the renewal funds.

The M.A.V. do so only in the case of these latter.

The percentages established are shown in Plate 22. It should be noted that the N.S. and the Czechoslovakian Railways relate these percentages to the present value of replacement, and the S.N.C.B. to the value of the bridge when new, calculated according to present price levels. It would appear that these two methods give very much the same result.

The Jugoslavian Railways take the value of the bridge when new as the basis, but they do not state whether it is the present day value or the cost at the time of construction.

Finally, the M.A.V. calculate the overall value of the bridges by taking into account in the case of old bridges, the real value as estimated at the end of the second world war, and the actual cost in the case of bridges built after the war.

The M.A.V. and the N.S. have fixed rates valid for all types of bridges, whilst the S.N.C.B. and the Jugoslavian Railways make a distinction between metal bridges, reinforced concrete and masonry bridges.

Finally, the Czechoslovakian Railways divide masonry and reinforced concrete bridges into several groups and fix different rates of maintenance and renewal for each group.

The Czechoslovakian Railways even deal with wooden bridges, and have fixed the following rates for these :

— wooden bridges protected against the weather :

maintenance rate	4 %
renewal rate	5 %

— pile work, assembled beams :

maintenance rate	6 %
renewal rate	15 %

1.22) *What are the costs (in national currency) in actual practice for the renewal and maintenance of bridges during the last five years, and how have these differed from the corresponding estimates?*

The replies to this question generally contained no reference to the number or length of existing bridges and consequently no comparisons are possible (see Plate 23).

It can merely be remarked that certain Administrations have not been able to provide for the regular maintenance of their bridges due to lack of funds and that maintenance costs are generally rather lower than the estimates. In the case of the S.N.C.B., it will be noted that the budgetary estimates were already somewhat lower than the amounts corresponding to the maintenance rates indicated in the reply to question 1.21.

On the contrary, the amount spent on renewal by the S.N.C.B., M.A.V. and N.S. were higher than the corresponding renewal rates. It may be remarked that the expenditure by the S.N.C.B. was all the same lower than the estimates, as these had been considerably increased for the reasons explained in the observations given in Plate 23.

[625 .143 .3]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

17th. SESSION (MADRID, 1958).

QUESTION 9.

Experience obtained concerning the undulatory wear of rails.
— Damaging effects on the track, bridges, viaducts and tunnels, and on the rolling stock.
— Research into the causes of this kind of wear.
— Measures taken to avoid or to remedy it.

REPORT

(Austria, Belgium and Colony, Bulgaria, Cambodia, Czechoslovakia, Denmark, Ethiopia, Finland, France and French Union, Western Germany, Greece, Hungary, Indonesia, Italy, Lebanon, Luxemburg, Netherlands, Poland, Portugal and overseas territories, Rumania, Siam, Spain, Switzerland, Syria, Turkey, Union of Soviet Socialist Republics, Viet-Nam and Yugoslavia),

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A. INTRODUCTION.

The present report is based on the information supplied and opinions expressed by those of the Railway Administrations and Organisations to which the questionnaire was sent and who were good enough to reply.

Below we list those from whom replies were received :

Austrian Federal Rys;
Belgian National Rys;
Belgian National Light Rys;
General Electrobel Co;
Liège-Seraing Ligh Rys and extensions;
Lower Congo to Katanga Ry;
Upper Congo to Great African Lakes Rys;
Colonial Transport Office (O.T.R.A.C.O.);
Czechoslovakian State Rys;
Danish State Rys;
Finnish State Rys;
French National Rys;
Société Générale des Chemins de fer Economiques;
Chemins de fer Economiques du Nord;
Parisian Transport Board (R.A.T.P.);
General Railway & Road Operating Co.;
Algerian Rys;
Gafsa Rys;
Tunisian Rys;
France Overseas Ministry;
Franco-Ethiopian Ry;
Morocco Rys;
Mediterranean-Niger Rys;
Viet-Nam Rys;
German Federal Rys;
Hungarian State Rys;
Italian Ministry of Transport;
North-Milan Rys;
Venitian Light Rys;
Luxemburg Rys;
Netherlands Rys;

Polish State Rys;
Portuguese Rys;
Swiss Federal Rys;
Bernese Alps Rys;
Rhaetian Rys;
Fribourg Rys;
Syrian State Rys;
Damas-Hama Ry and extensions;
Jugoslavian Rys;
Union of Soviet Socialist Republics (U.S.S.R.) Rys;
International Sleeping Car Co;
Deutsche Schlafwagen und Speisewagen Gesellschaft (German Sleeping Car and Restaurant Car Co);
International Railway Union;
Union of Railways;
Swiss Transport Undertakings Union;
Greek State Rys;
Spanish National Rys;

We have not yet received any replies from some twenty other Organisations consulted.

The Administrations, which were able to supply more or less extensive information on this problem, were the following :

German Federal Rys;
French National Rys;
U.S.S.R. Rys;
Swiss Federal Rys;
Belgian National Rys;
Belgian National Light Rys;
Rhaetian Rys;
Danish State Rys;
Italian Ministry of Transport;
Paris Transport Board (R.A.T.P.);
Netherlands Rys;
Tunisian Rys;
Gafsa Rys;
Algerian Rys;
Czechoslovakian Rys;
Finnish State Rys;
Chemins de fer Economiques du Nord;
Société Générale des Chemins de fer Economiques (France);
Viet-Nam Rys;
Austrian Federal Fys;
R.E.N.F.E.

The remaining Administrations who were good enough to reply informed us that they were not able to give any useful information.

In the present report we will examine first of all the data supplied by the Administrations consulted, taking into account the opinions and information given in the replies received.

* * *

B. RESUME OF THE OPINIONS AND INFORMATION RECEIVED.

Question I. *General.*

I. — 1) *Are all types of undulatory (corrugated) wear fundamentally similar or have different types been noticed ?*

Have you made any classification of the different types of undulatory wear? Any statistical data ?

I. — 2) *Relative values of the different types of undulatory wear from the point of view of the frequence with which they occur, their extent, etc... taking into account the length of the undulatory wave, its amplitude, the surface structure of the metal, etc.*

Summary of the replies :

German Federal Railways. — There is a definite distinction between undulatory wear having small waves, which is found almost exclusively on the main lines, the length of the waves being 3 to 8 cm, and undulatory wear having large waves, from 8 cm to greater than the width between sleepers, which is found above all on lines run over by trains of homogeneous composition running at uniform speed, like electrified suburban lines and urban systems.

In most cases undulatory wear of small wave length has bright, polished crests of variable form : continuous raised surfaces in the form of bands, longitudinal, transversal, pointed, or sawtooth like bosses; double or ladderlike bosses, etc. The

depressions are dull and rough. Whilst wear having long large wave lengths is rough over both the crests and hollows.

No statistics are available concerning the respective percentages of the different exterior characteristics that are met with.

It is short wave undulatory wear, especially in the form of pointed bosses, that results in the greatest inconvenience.

Comparative measurements made on lines having very varying conditions of service have shown that there is no appreciable difference between the inclination of the ascending and descending tangents of the crests. The most usual size of the waves is 4.3 cm, with average depths of 0.12 mm.

French National Railways. — Undulatory wear having short waves, with harder crests and rough hollows filled in with the waste material resulting from the wear is commonly found on straight sections in the open line. 20 % of the mileage of the main lines on the system suffer from this type of wear. Wear having short waves has also been noticed in zones where braking occurs, near stations, and on a few curves of small radius, but kinds of wear of lesser extent than the first.

The type of undulatory wear having long waves is noticed above all on the electrified suburban lines, rarely on lines with steam traction. It affects in particular rails laid within the last 25 years and seems to be a normal type of deterioration. Similar wear with permanent deformation of the rail between sleepers occurs in certain cases, especially in the case of old, light rails.

Undulatory wear with long waves is characterised by the depth of the waves, generally more than a millimetre, exceptionally as much as 5 mm. On the other hand, that with short waves is generally only about 0.1 mm, exceptionally as much as 0.3 mm. The short type is characterised by the natural hardening of the crests which occurs, whilst with the long type this phenomenon does not occur.

No statistics are available concerning the different forms of undulatory wear.

Union of Soviet Socialist Republics Railways. — Undulatory wear is of very varied types, both as regards form and size, but no systematic classification of the different types has been established.

The wear is fundamentally different according to whether it is a case of main lines or tramway lines. On the former, wear occurs in the form of waves whose length varies from 0.2 to 2 or 2.5 m. On tramway lines the wear occurs in the form of short waves, from 6 to 8 cm in the case of lines on a concrete foundation, 10 to 20 cm in the case of lines whose foundations are made of ordinary ballast.

On railway lines the depth varies from 0.1 to 3 mm. In certain isolated cases up to 6 mm. When the wear exceeds 3 mm fairly severe crushing of the railhead is noted. On tramway lines, the rail becomes polished when the wear exceeds 0.1 mm.

Swiss Federal Railways. — Two types of undulatory wear have been noted agreeing with those noted as fundamental on the S.N.C.F. and D.B. These 2 types, with long or short waves, are found simultaneously on the same sections suffering from undulatory wear. The structure of the metal, on which the wear occurs, is characterised by the presence of martensitic constituants on the crests; the work hardened depressions show a ferrite perlite structure. The running surface of the rails with long wave undulatory wear generally has a ferrite perlite work hardened structure. Certain rails are affected by deformation due to fabrication; others become deformed under the action of the stresses due to the traffic.

Rhaetian Railways. — On all the lines of the narrow gauge system, there is undulatory wear with long waves, of amplitude of up to 0.8 mm and 1.5 mm. The short wave wear is of little importance.

Danish Railways. — The two types of undulatory wear — short and long — have been noticed with the classic characteristics. No statistics are available, but the wear having long waves is more serious, with waves of between 150 and 600 mm with depressions of 0 to 4 mm.

Algerian Railways. — Undulatory wear with small waves, from 3 to 5 cm and depressions of 0.1 to 0.3 mm and wear with long waves, from 0.9 to 1.3 m with depressions of 1 to 2.5 mm.

Belgian National Light Railways. — Small and long waves, the latter from 30 to 40 cm. No statistics available.

Austrian Railways. — Short undulatory wear only occurs on 1.6 % of the system. Long undulatory wear, up to 40 cm has only been noted on a few curves of small radius.

Belgian National Railways Company. — The undulatory wear noted is essentially of the classic short wave type. On certain lines, short waves have been noted whose crests as well as depressions are bright; the wear then affects the whole width of the railhead.

Tunisian, Gafsa, Viet-Nam, Czechoslovakian Railways. — Only short wave undulatory wear has been noted, averaging 4 cm in length.

Paris Transport Board (R.A.T.P.). — Several types of waves from 4 to 60 cm long have been noticed. No statistics available.

« Chemins de fer Economiques » (France). — The undulatory wear noticed has short waves. Lengths of 25 to 50 mm on the standard gauge lines and 15 to 30 mm on the metre gauge lines. Depressions of the order of a tenth of a millimetre.

Finnish Railways. — Short wave undulatory wave is insignificant. Long waves have been found in the case of very worn rails.

R.E.N.F.E. — Wear with short waves, with the classic characteristics, has been noticed, with little depth. Long waves seldom occur. No classifications have been made.

I. — 3) *Where do the different types of undulatory wear occur, for example on straight sections or on curves? In the case of curves, between what limits of curvature?*

I. — 4) *Comparison of undulatory wear on the two lines of rails of the same track, on curved track and on straight track.*

Summary of the replies :

German Federal Railways. — Short undulatory wear occurs in the main on straight sections and curves of large radius. Undulatory phenomena have been noted in zones where long distance braking takes place, and on the outer line of rails on some small radius curves.

Undulatory wear may occur on either one line of rails or on both, for reasons which appear to be related to the material of each rail, without it being possible to establish any influence due to placing the rails in one or other line.

S.N.C.F. — Short wave undulatory wear on straight sections is the most important. The undulatory type of wear in braking zones occurs mainly on electrified lines, and short wave wear on curves of small radius is only frequent on secondary systems. The wear may affect one line of rails or only certain rails of the same line, or else rails of both lines. The fact that a rail is placed in one line or the other has no influence. In the case of long wave undulatory wear, the pseudo-period can

vary along the same rail. Although similar to the sleeper spacing, it rarely coincides with the sleeper arrangement and it occurs on the longitudinal sleepers of metal bridges. On curves, the most pronounced corrugations are on the most heavily loaded rail.

U.S.S.R. Railways. — Undulatory wear has been noted on straight sections but occurs above all on curves. The amount of wear on railway lines as well as tramways increases inversely as the radius, up to curves of about 300 m radius, according to the results of numerous measurements carried out on rails all fabricated by the same works and laid the same year. On curves of less than 300 m radius, the intensity of the wear decreases with the radius and when the radius is below 75 m is no longer noticeable.

Shorter waves have been noted on curves than on straight sections. No appreciable difference has been noted between the wear on the two lines of rails.

Swiss Federal Railways. — Short waves generally occur in the braking zones and curves of small radius. The classic wear on straight sections is very rare. Long wave wear is more frequent on electrified lines, perhaps on account of the influence of the load and speed characteristics. On curves, wear more frequently occurs on the outer rail. On straight sections there is no difference.

Rhaetian Railways. — Wear occurs on both straight sections and curves. The smaller the radius, the greater the wear. On curves, the outer rail generally shows the most wear.

Danish Railways. — Long wave type undulatory wear is the most frequent, and appears on all types of track, on gradients, slopes, curves, and straight sections, on soft ground as well as hard ground. Short waves are more frequent on straight lines.

Belgian National Railways. — The two types of wear are seen both on curves and straight sections. Generally, the waves have greater amplitude on the inside rails of double track straight sections, a difference which appears to be due to the greater rigidity in the bed of the track in the middle between tracks.

Tunisian Railways. — Observation has been kept of the relation between the form of undulatory wear and the place where it occurs. The triangular and mushroom shaped forms are noticed on gradients; the arcade type on curves; the elongated and isolated type on straight sections; the ridge type both on curves and straight sections.

The wear on the two lines of rails of the same line often shows a difference as regards the length of the waves and the distribution of the irregularities. On curves of small radius, undulations occur on the outside line, the inside line showing continuous wear.

Netherlands Railways, Belgian National Light Railways, Algerian, Czechoslovakian, Gafsa Railways and R.E.N.F.E. — Their observations agree concerning the amount of undulatory wear on straight sections, though it also appears on curves. No co-relation between the wear on one line of rails compared with the other.

Paris Transport Board (R.A.T.P.), Chemins de fer Economiques (France). — The most frequent types of undulations are those noticed in braking zones and curves of small radius. No influence noticed on straight sections on the wear due to the position of the rail.

Remaining Administrations. — No observations of importance, but nothing that contradicts the general tendency shown by the other replies.

I. — 5) *In the case of wear known as « roaring rails », what is the range of the pitch and depth of*

undulatory wear. Does the pitch and depth vary with the average speed of the trains that run over the line in question?

Summary of the replies :

German Federal Railways. — Noise occurs when trains pass when the depth of the undulations exceeds 0.08 mm. Its pitch is a function of the speed and the spacing of the crests. The sound level is influenced by the depth of the undulations and by the penetration of the wheels, small diameter wheels giving a higher pitch.

S.N.C.F. — The amplitude of short wave undulating wear, characteristic of roaring rails varies from 0.1 to 0.3 mm. It does not appear to have any connection with the speed of the train, but rather with the diameter of the wheels and the axle loads.

U.S.S.R. Railways. — The type of wear known as roaring rails is only observed on tramway lines. With such wear it has been noticed that the amplitude is displaced towards the trajectory of the highest part of the wheel, as a function of the speed of the trains at which roaring occurs.

Swiss Federal Railways, Danish Railways, Netherlands, Algerian, Tunisian, Gafsa, Finnish, Czechoslovakian, Chemins de fer Economiques, R.E.N.F.E. — The phenomenon known as roaring rails is known to occur with amplitudes varying from 0.1 to 0.3 mm. It has not been noticed whether there is any relation between the amplitude and the running speed. In general, it is considered that the undulations increase with the speed.

Rhaetian Railways, Belgian National Light Railways, Austrian, Viet-Nam, S.N.C.B., Paris Transport Board (R.A.T.P.) :

The phenomenon of roaring rails does not seem to be known or to a very small extent. There are no short waves, or not enough to cause this characteristic noise.

I. — 6) *Formation and evolution of undulatory wear.*

a) *time between the laying of the track and the appearance of the first signs of undulatory wear;*

b) *the pattern of the undulatory wear from its beginning and its growth;*

c) *whether the existence of a joint has any effect on the regularity of undulatory wear waves;*

d) *facts observed in connection with rails with undulatory wear that have been reversed;*

e) *evolution of undulatory wear that started with accidental or artificial damage.*

In particular, phenomena observed with welded rails (electric, aluminothermic welding, etc... welded rails of different metallic compositions).

Summary of the replies :

German Federal Railways.

a) In the case of some rails, several years elapse before the first signs appear. In the case of other rails, it appears after a few weeks.

b) As soon at it starts undulatory wear develops in different forms, in relation with the nature of the rail, the place where it is laid and the service worked over it.

c) The undulations often stop at the joint, but in certain cases it extends beyond the joint for 1 to 2 m. In many cases, there is a certain irregularity in the waves near the joint.

d) No valid conclusions are possible. In certain cases, the undulations become less, in other cases they remain constant, or even increase in extent.

e) In the case of welded rails, it is found that certain parts made up from rails of different kinds show undulatory wear, whilst others remain free from it.

S.N.C.F.

a) Short undulatory waves sometimes are apparent a few days after laying. In such cases of premature wear it appears that this is due to the fabrication of the rails. The proportion of rails affected is a function of the age of the rail on the line : in the case of one year in service 2 %; 4 years, 10 %; 7 years, 27 %, according to statistics collected on the main lines.

b) The form of the waves appears to be disymmetrical at first. In time, they evolve both the point of view of their form and their position. If the temperature on the rail surface can reach a high enough value to result in superficial hardening of the crests, the increase in the hardness of the tempered part increases the amplitude of the undulations and at the same time stabilises their position. If such a phenomenon does not occur stabilisation of the amplitude of the wear occurs at the same time as this moves along the rail in the direction of running. The first form of wear is the most harmful and most frequent.

For any given rail, wear in all its forms increases with the time since it was laid. Short wave wear is characterised by the regular increase soon after laying, followed by a certain tendency towards stabilisation. On the other hand, wear with long waves shows no change in the rythm at which it increases. The regularity of the undulatory wear increases with its amplitude.

c) The zones in line with the fishplates are generally less subject to it than the remainder of the rail.

d) Every rail showing undulatory wear has remained worn in this way after being taken up or reversed, and every rail free from it has remained free from it. As expected the undulations were more or less changed after a certain time due to the influence of the change in the direction of the trains on the rail.

e) Rails have been laid in the track which were artificially undulated over half their length. This wear showed no signs of increasing; it gradually diminished. It has happened that in the case of two welded rails one section develops undulatory wear whilst the other remains free from it.

U.S.S.R. Railways.

a, b) Over a great part of the permanent way slight undulatory irregularities can already be noticed before the rails are laid. The increase in this type of wear depends upon the size of the initial irregularities, tonnage carried, etc. On Phoenix type tramway lines with the rails embedded in concrete up to the top of the railhead, the first signs of wear occur 5 to 7 days after they are put into service. In the case of rails laid on ordinary ballast, wear shows above all in the winter when the frozen ballast behaves like concrete.

c) On the main lines, a characteristic irregularity is noticed in the waves in the region of the joints which does not extend over the rest of the rail. On tramway lines, irregular wear starts at the joints and spreads over the whole rail.

d) No systematic proof has been obtained of the effects of changing the position of the rails. In some isolated cases, such a change has eliminated irregularity of wear.

e) One accidental source is the skidding of the locomotive wheels, which produces local effects on the main lines. On the tramway lines, on the other hand, similar wear occurs over the whole line.

Swiss Federal Railways.

a, b) Short undulatory wear is sometimes observed a few days after the rails have been laid. It only becomes harmful after some 5 to 6 years. Long wave wear can be due to the fabrication of the rails or otherwise. In any cases, it increases with the time the rail has been in service.

c, d, e) No special observations.

Rhaetian Railways.

a) Undulations have been noticed on new rails 9 months after they were laid, but generally only occur after 2 to 3 years.

b) The first form in which such wear appears is not modified as time goes on.

c) In the case of long wave wear, near the joints, the lengths are usually somewhat greater than the space between the sleepers. In the middle of the rail they are usually rather shorter.

d, e) Welded rails show the same undulatory wear as non-welded rails. There is generally a wave near the weld.

Danish Railways.

a) In only one case has the formation of long waves been noticed as early as 4 months after laying (50 000 gross tons per day). In another case, the rails remained 20 years without undulatory wear, but after a further 12 years short waves occurred to such an extent that grinding became necessary (4 500 000 gross tons per annum).

b, c, d, e) No observations.

Netherlands Railways.

a) The first traces of undulatory wear are seen two years after the rails are laid. In one case, it was noticed after a year and a half.

b, c, d) It has been noticed that there is a difference in the length of the waves according to the works that made the rails.

e) With two different kinds of rails welded together, sometimes one shows undulatory wear and the other does not.

S.N.C.B.

a) From three months to a few years.

b) The result seems to be that the waves move along the rail as time goes on.

c) A different distribution of the waves is noticed near the joints, probably due to the heat treatment the ends receive.

d, e) No observations.

Tunisian Railways.

a, b) The phenomenon has been noticed on lines renewed during 1950 (36 kg rails, metre gauge line) and in 1953 (46 kg rails, standard gauge line).

c) On one double track section it was found that the end of the rail before the joint was generally either free from undulatory wear, or affected by wear with a different length of wave, which gradually harmonised with the average length of the waves over the rest of the rail.

d, e) No observations. Only worn rails have been welded.

Belgian National Light Railways.

a, b) Apparition of undulatory wear after a very variable period, one year in some cases, the wear aggravating the more rapidly as there are more irregularities in the rail, such as fishplated joints, marks made by vehicles, etc.

c, d, e) No observations.

Chemins de fer Economiques (France).

a.....e) Towards the ends of the rails, on a distance of 30 cm, undulatory wear is sometimes less marked.

Czechoslovakian Railways.

a, b) Apparition of undulatory wear 1 to 2 years after laying.

c) In some cases the waves disappear near the ends of the rail.

d) Same wear observed in the case of welded rails as non-welded rails.

Finnish Railways.

a.....e) In one 13 km long section with 30 kg rails, the first undulatory wear noticed was 50 to 70 cm long and after 8 years it has shortened to about 20 cm. Deflection up to 2.4 mm.

R.E.N.F.E.

a, b) The beginning of undulatory wear with short waves has been noticed within two years of laying new 45 kg rails.

c) Near the joints, the wear is sometimes irregular, confused and in some cases very small.

d) Similar wear observed with welded as with non-welded rails.

Remaining Administrations. No observations.

I. — 7) *Have you compared rails having undulatory wear with those which have none, taking as factors for such a comparison :*

a) *the wear of the head;*

b) *the age of the rails;*

c) *the frequency of broken rails.*

Summary of the replies :

German Federal Railways.

a, b) The wear of the head is smaller in the case of rails with undulatory wear which are harder than those without it. After some twenty years, the undulated rails only show a wear of 5 to 6 mm whilst those without it wear 8 to 9 mm with the same traffic.

c) No relation between broken rails and undulatory wear has been noticed.

S.N.C.F.

a, b) Short undulatory wear most often affects rails whose general wear is small. Long wave undulatory wear occurs above all on old and very worn rails.

c) Rails with short undulatory wear very rarely have any cracks due to fatigue. The exception is heat treated rails where undulatory wear seems to precede the generalised flaking of the running surface.

U.S.S.R. Railways.

a, b, c) Irregular wear has an extremely great influence on the useful life of rails. On a line in the Urals, the rails had to be replaced 4 to 5 years after laying, with wear of 4 to 5 mm in depth. On the tramway lines, broken rails have been noted due to the fact that the rails were not polished in time.

C.F.F., R.E.N.F.E.

a, b, c) No statistics are available, but it has however been found that rails with little specific wear are those generally most subject to short wave undulatory wear.

Remaining Administrations. — No special observations.

II. Influence of the component elements of the track upon undulatory wear.

II. A. — The rail.

II. A. — 1) *Is there any proof that the composition and method of fabricating the rails may influence the tendency to undulatory wear?*

a) *composition of the steel, its hardness;*

b) *size of the ingot;*

c) *vibrations during rolling and irregular, non-uniform cooling;*

d) *methods used in straightening the rails after rolling;*

e) *observations on segregation.*

Summary of the replies :

German Federal Railways.

a) The differences in the composition of rails affected or free from undulatory wear are very little, and concern the carbon and manganese contents. Martin Siemens rails with a small amount of nitrogen are generally less liable to undulatory wear than Thomas steel rails.

b, c) The size of the ingot, the vibrations of the rolls of the mill, and irregular cooling all appear to have some influence.

d) The straightening of the rails after rolling is done in an upright position on the D.B., by means of modern straightening machines with rollers. Rails which have had to undergo a heavier degree of straightening have shown certain signs of undularory wear after being laid.

e) It has not been possible to ascertain if the ordinary segregation of the ingots has any influence upon the formation of undulatory wear. On the other hand, the so-called crystalline segregation accompanied by the formation of dendrites may very well be favourable to such wear. Studies being made by the D.B. on this point have not yet been completed.

S.N.C.F.

a) Rails that have been heat treated (sorbitic and martensitic structures) are more susceptible than ordinary rails to undulatory wear.

The proportions of carbon and manganese have an influence upon the hardness of the rails and very hard rails appear to be the most susceptible to undulatory wear.

According to certain observations made with rails laid between 1948 and 1953, from various steel works, the percentage of rails with undulatory wear varies with the source of supply and time in service, but is also affected by the individuality of each rail. Sometimes the percentage of rails from the same source of supply with undulatory wear is greater in the case of rails that have been a shorter time in service.

It has been found that certain rails with undulatory wear include a high proportion of silicon and nitrogen, and that Martin Siemens steel rails are less susceptible than Thomas steel rails to undulatory wear.

b) It appears that short wave undulatory wear usually occurs on rails from big ingots which have undergone less work in the rolling mill.

c) It appears that the undulatory wear which occurs with H.T. (heat treated) rails shortly after they have been put into service is partly due to lack of uniformity in the cooling when they are tempered in the works.

d) It has been found on numerous occasions that rails with undulatory wear have no signs of such wear at the ends over a length of 25 to 40 cm.

Rails coming from steelworks where the rails are straigthened in the flat position show less undulatory wear than those from works where this is done with the rails upright. In the same way, there is little undulatory wear in the case of rails fabricated in works where the rails are cambered under heat before being straightened.

e) It has not been possible to find any relation between undulatory wear and the distribution of the segregations.

U.S.S.R. Railways.

a, b) These influences have not been exactly determined.

c, d) New rails show irregularities which occur during fabrication; while they are being moved about whilst the steel is still very hot, and during cooling when this takes a long time. When rolled cooled down, the majority of such irregularities are eliminated. Any interruption in operation of the straightening equipment may cause additional irregularities, spread over the whole length of the rail. Other irregularities can be ascribed to the rails going through the marking presses.

Swiss Federal Railways.

a) Heat treated rails show more signs of undulatory wear than untreated rails. In the case of rails fabricated in the same fashion and coming from the same works, there may in addition be a relation between the liability of the rails to undulatory wear and the C/Mg ratio.

b) The size of the ingot seems to have some influence.

c, d) Vibratory phenomena either during rolling or during straightening, seem to be the cause of undulatory wear in particular.

e) No observations.

Remaining Administrations. — No systematic observations. Experience confirms in general that the composition of the rails has a certain influence upon the formation of undulatory wear, as well as the method of fabrication. In general, wear has been noted less frequently with Martin Siemens steel rails than with Thomas steel rails.

II. A. — 2) Other factors :

a) *Weight and length of the rails, limits of elasticity, moment of inertia, form of the profile, and in particular the design (width, curvature, radii) of the running surface;*

b) *use of welded rails;*

c) *use of check-rails;*

d) *widening of the gauge.*

Summary of the replies :

a) The data concerning short wave undulatory wear collected by most of the Administrations generally differ from those collected concerning long wave wear. Short wave wear affects rails of all weights and all moments of inertia. The weight and length of the rails does not appear to have any appreciable influence. The modulus of elasticity may perhaps have a certain influence, as shown by the measurements made by the D.B. by means of an elasticimeter. The moment of inertia may also have an influence perhaps, but the attempts made to prove this by trying to influence the vibrations of the rails by making hollow places in their profile have been successful. Excessive curvature of the head appears to be unfavourable as it increases the rail wheel contact pressure. In general the configuration of the running surface and profile can contribute to the varying aspects of undulatory wear on the different lines.

Long wave undulatory wear occurs the more as the weight, the moment of inertia, and the limit of elasticity of the rails are smaller. This wear is more extensive on light rails, whereas short wave wear more frequently affects heavy rails and is seen less often on light rails. As short wave wear shows at first as periodic variations in work hardening, an increase in the limit of

elasticity when cold would be advantageous, but this would have the drawback of increasing the probability of the phenomenon of the self-hardening of the crests occurring.

b) In the case of track laid with long welded rails no difference has been noted in the features of undulatory wear compared with that occurring on the ordinary lines (D.B.) (S.N.C.F.) (R.E.N.F.E.). Replacing a joint by a weld does not cancel out the formation of undulatory wear, but perhaps reduces its intensity.

In the U.S.S.R. on tramway lines, undulatory wear often begins at the top of the welded joints. On the main lines, no such phenomenon has been noted. On the National Light Railways Company, undulatory wear occurs more often with Vignoles rails, 32 kg, 54 m long, than in the 51 kg grooved rails that are completely welded. On the R.E.N.F.E. rails welded three years ago show a small amount of short wave undulatory wear, similar to that which occurred on non-welded rails of the same type in the same section.

To sum up, experience has generally gone to show that welding rails has little effect on the beginning of undulatory wear. It remains to be seen whether the evolution will differ or be slower as time goes on.

c) It has been noticed fairly frequently by some Administrations, S. N. C. F., R.E.N.F.E., etc., that undulatory wear disappears at level crossings fitted with check-rails, perhaps because of the artificial increase in the moment of inertia due to the check-rail. On the Austrian Railways, the check-rails were removed on certain curves showing heavy undulatory wear, but nothing can be deduced as yet, as this was done too recently.

d) Widening of the gauge may have a certain effect, but in any case it is advisable to reduce the play of the vehicle axles on the track to reduce the movement and effects of the rolling stock on the permanent way.

II. B. — The sleepers :

a) *shape;*

b) *material;*

c) *spacing.*

Summary of the replies :

D.B.

a, b) Soft wood sleepers, with their great elasticity, tend to give rise to rather increased undulatory wear than the more rigid hardwood or steel sleepers. As for concrete sleepers, as it is not long since these were laid, no statistics are available.

c) On a trial section, with sleepers spaced at 50, 60 and 75 cm, measurements were made which showed that if the amplitudes of the oscillations of the rails and axles varied, the frequencies remained practically identical.

S.N.C.F.

According to certain trials carried out with rails laid between 1951 and 1953, from various steelworks, half of which were laid on wood sleepers without elastic fastenings and the other half on concrete sleepers with elastic fastenings, it was found that the percentage of rails attacked by undulatory wear is extremely variable, and that no precise law can be determined as to the influence of the type of sleeper and method of fastenings. The use of concrete sleepers on the whole appeared rather unfavourable.

In the case of long wave undulatory wear, the stocks at the joints and deflection of the rails have an influence, and a closer sleeper spacing seems to be unfavourable.

U.S.S.R. Railways.

Wood sleepers are mainly used. Wear is similar with different sleeper spacings.

Remaining Administrations.

No difference found as a rule as regards the influence of the type and spacing of the sleepers. On the S.N.C.B., it was found that metal sleepers tended to favour wear, whereas on the Tunisian Railways wear occurred above all with wood sleepers. Short distances between sleepers seem to lessen long wave undulatory wear. On the Belgian National Light Railways (S.N.C.V.), the number of sleepers per 18 m length was increased from 18 to 25 without any appreciable effect. On the N.S. a reduction in undulatory wear was noticed after laying type RS concrete sleepers with RN type fastenings. On the R.E.N.F.E., undulatory wear is noticed with concrete sleepers 3 years after laying, but also on wood sleepers after the same time, with a similar aspect.

II. C. — The ballast :

a) *material;*
b) *size;*
c) *thickness of the layer of ballast.*

Summary of the replies :

C. *a, b, c*) On the D.B., the usual size of ballast is used, between 35 and 65 mm. The thickness of the layer seems to have a slight influence, seeing that in tunnels for example, where there is a thinner layer of ballast and a hard subsoil, undulatory wear is more pronounced than on lines in the open with the ordinary thickness of ballast.

In general, the impression appears to be that a good layer of ballast helps to reduce the effects of undulatory wear, but no exact ratio has been established between the kind and size of ballast and undulatory wear. Rails of the same fabrication laid on different balasts showed more or less the same wear.

II. D. — The bed

Summary of the replies :

Rails with undulatory wear are found on the most divers types of soil without much difference. A few Administrations have found that a rocky bed has a certain unfavourable influence. On the U.S.S.R. on tramway lines with rails embedded in concrete, there is intense undulatory wear. On the Metropolitan lines with wood sleepers embedded in concrete, the wear was very similar to that on the railway lines. On the North Light Railways pronounced wear was noted at two metal bridges (Broca rail) where the track was laid on a bed without elasticity. On bridges with check-rails and Vignole rails, no undulatory wear was noted.

II. E. — The joints :

a) *supported;*
b) *overhanging;*
c) *square or staggered.*

II. F. — Fishplates :

Types.

Summary of the replies :

SN.C.F.

The behaviour of supported joints is the same as that of overhanging joints with the same type of fishplating. The doing away with the overhang will only avoid a shock at the joint if their bed is undeformable.

Vertical movements are more pronounced as the fishplating has less inertia. Fishplates that are very rigid vertically have a high mass and act as an anvil under the impact of the wheels, with harmful dynamic effects.

U.S.S.R. Railways.

The results of measurements made of the undulatory wear on 6 400 rails from different sources showed that such wear was present in 61.4 % spread over the whole length of the rail; in 10.8 % it only occurred in the central part; in 5 % only at one end. No influence characterised by the type of joint has been observed. Undulations developed near the welds did not extend over the rest of the rail.

Remaining Administrations.

On the D.B. no influence from the joint arrangement has been noticed, joints supported on twin sleepers being used almost exclusively. On the S.N.C.B., it has been noted that heat treatment of the ends of rails has the effect of causing crests to appear in the form of a continuous zigzag over the whole of the treated portion. In general, it is agreed that the method of fishplating has an influence on the behaviour of the waves, but no comparisons have been made. On the R.E.N.F.E. the waves have been found to be irregular or to disappear near the ends of the rails; as also on the Czechoslovakian Railways and a few others.

III. Influence of factors extraneous to the track.

III. A. — Factors concerning the type of rolling stock and its construction :

a) *type of traction (steam, electric, motor units);*

b) *type of drive (direct, gears, rods);*

c) *mass and power of the motors;*

d) *axle journals (bearings, roller bearings, dimensions — diameter and length —);*

e) *diameter and profile of the tyres;*

f) *type of and material used for the brake shoes;*

g) *type of shock absorbers and vibration dampers;*

h) *arrangement and spacing of the driving and carrying wheels;*

i) *weight and distribution of the loads on the axles;*

j) *effects of loaded and empty vehicles;*

k) *ratio of the non-suspended weight to the total weight of the vehicles.*

Summary of the replies :

a) There is proportionally greater undulatory wear on electrified lines, especially on electrified suburban lines (S.N.C.F.). Undulatory wear is also more intense on electrifed lines in the U.S.S.R., and similar remarks were made by the C.F.F., especially in the case of long wave undulatory wear, and the Danish Railways where, after the electrification of the Copenhagen suburban lines, important long wave undulatory wear occurred after a few years, and the extension of the long waves has been related to dieselization. On the Rhaetian Railway only electric traction is used, it having been noticed that the wear was similar on lines with railcar services only to that on lines where locomotives were run. On the D.B., no difference in the undulatory wear according to the method of traction has been noted, nor as regards the length of wave, nor the amplitude, nor the type of wear.

b, c) Driving the axles by an elastic device which is not damped out, with initial recall and linear elasticity, seems to favour the formation of undulatory wear. The probability that the temperature at which hardening takes place will be reached is less when the

same power is distributed over a greater number of successive axles. The mass in the case of motors that are not completely suspended increases the dynamic stresses (S.N.C.F.). The same observation is made by other Administrations concerning the bad effects of unsprung weight.

d) No observations.

e) The uniformity of the principal diameters of the wheels and their profile, material and type of construction appear to be unfavourable (D.B.). A small diameter is unfavourable, especially in the case of heavily loaded locomotive wheels; it appears that the putting into service of electric bogie railcars with small diameter wheels has favoured the development of undulatory wear on the Belgian National Light Railways (S.N.C.V.). The conicity of the tyres plays a part in the elastic torsion of the axles, especially on curves. The carrying axles can give rise to undulatory wear when their frequency of torsion is close to their principal frequency of vertical vibrations on the rail (S.N.C.F.).

f) Ferrodo brake blocks seem less harmful than cast iron shoes for the braking areas and curves.

g) It appears that the damping out of the vibrations caused by the wheels should reduce the dynamic stresses of high frequency to a small value, which does not favour the formation of undulatory wear, but up to the present no relative results are available.

h) It appears that there are certain critical distances between successive motor axles which may favour the formation of undulatory wear, owing to the coupling between their vertical vibrations, but no experiments have been carried out on the subject.

i, j) From the observations made by the D.B. and some other Administrations it appears that undulatory wear is greater on lines that are run over by a large proportion of empty wagons. On the other hand, in the U.S.S.R., the opposite has been established, seeing that the wear is greater on lines where the vehicles always run heavily loaded.

k) The dynamic stresses are the greater as the ratio between the non-suspended mass and the total weight is the greater. The bad effects of locomotives with nose suspended motors is stressed by the S.C.N.F. and some other Administrations.

III. B. — Effect on the growth of undulatory wear of :

a) *frequency of the services;*

b) *speed of the trains.*

Summary of the replies :

a) Greater undulatory wear is generally found on lines with heavy traffic. Additional traffic leads to acceleration of undulatory wear; according to most of the Administrations such phenomena exist in serious proportions. In the U.S.S.R., the measurements made have enabled empirical formulae to be established giving the intensity of the development of the wear according to the initial deformation of the rails and the tonnage running over the line. This development is accentuated after a certain tonnage has been carried.

On the S.N.C.B., it has been noted that electrified lines with frequent services nearly always show the type of undulatory wear with short waves with polished crests and hollows.

b) Undulatory wear develops both on lines with purely passenger services with express trains, and on freight lines with lower speeds, according to most of the Administrations. The length of the waves does not appear to be a function of the speed (D.B.). It appears that an increase in the speeds

is harmful on the whole (S.N.C.F., N.S.). In certain cases an increase in the speed of the trains produces a sort of polishing of the irregularities in the track in the case of long wave undulatory wear, according to observations made on the outer rail of a curve of 420 m radius (U.S.S.R.). To sum up, the evolution of the wear is a function of the traffic carried, in which the frequency may perhaps play a more important part.

III. C. — The surroundings :

a) *Humidity (neighbourhood of watering places, industrial plants, proximity to the sea, tunnels, etc.);*

b) *level of the water table.*

Summary of the replies :

a, b) On the S.N.C.F., no undulatory wear has been noted in tunnels, even those run through by steam trains where the humidity is great. Nor is there more wear on lines in industrial regions or close to the sea. On the other hand, the C.F.F. and German Railways find that short wave undulatory wear also occurs in tunnels; in North Germany, the wear is more frequent than in South Germany, where the air is less humid.

The water level of the soil may have an influence as this modifies the elastic behaviour of the soil.

III. D. — Homogeneous or diverse traffic :

a) *Combinations due to the factors collected under A.* a), b), i) *and B.* a) *and* b).

b) *Observations made on adjoining tracks and in the stations.*

c) *Has wear been found to differ when there are certain particular types of traffic, for example : express passenger trains, freight traffic, passenger traffic, local traffic with frequent accelerations and braking?*

d) *Does the frequence and development of undulatory wear differ according to whether it is a case of single track sections with trains running in both directions, or double track sections carrying similar traffic where the trains run in one direction only?*

e) *On double track sections on gradients, is the undulatory wear affected by the gradient?*

If so, is the wear more pronounced uphill or downhill according to the direction of the traffic?

Summary of the replies :

a) The combinations given have not yet been studied. Generally, it is admitted that the homogeneity of the train running and types of motor stock are two factors which affect the development of undulatory wear in all its forms. The extension of the wear may be favoured by dieselization, according to the observations of the Danish and Tunisian Railways, on lines where only engines of this kind are running. The importance of the influence of the non-suspended mass is the determining factor, according to several replies. In the U.S.S.R., it is noted that the waves tend to diminish when the load and speed of the trains are increased.

b) Near stations, especially on electrified lines, there is generally very variable undulatory wear, close to the braking areas. On the lines in stations, there is no undulatory wear or very little. Only some Administrations (Rhaetian

Railways, U.S.S.R.) report such wear as normal.

c) Wear is more pronounced in the case of passenger or freight traffic with frequent accelerations and brakings. It is small where trains run with great tractive effort. A bad profile increases the development of the wear. On lines having a homogeneous traffic, with heavy accelerations and decelerations, undulatory wear with short or average waves seems to be accentuated, but it is possible that the characteristics of the motors are also responsible for this result. When the type of traffic or speed of the trains varies on a line, in some cases a slowing down of the wear is noted. A certain polishing of the rails has even been noticed (U.S.S.R.). On the Tunisian Railways, the most marked wear was found on a double track suburban section with predominantly local stopping passenger services.

d) On double lines, the frequent bosses are inclined towards the axis of the track, whereas they are perpendicular to it on single lines, according to observations made on undulatory wear with short waves.

e) Most of the Administrations find that on double lines, undulatory wear is rather more marked on the down line. On the C.F.F. and U.S.S.R., similar wear has been noted on both up and down gradients. Though steep down gradients may lead to more pronounced undulatory wear, this may also be due to the effects of braking. On the D.B., statistical studies have shown that usually lines where the trains run down the gradients are generally less affected by wear than those where the trains climb up the gradients.

IV. Tyre-rail.

a) *Theories, practical trials and statistical inquiries, taking into account* on the one hand *the physico-chemical characteristics of the rail (steel composition, hardness, high limit of elasticity, large moment of inertia, wider running surface)* and on the other hand, *the effects of the thrust, compression, friction and sliding of the tyre on the rail;*

b) *Special observations in connection with the lessening or accentuation of undulatory wear by skidding, braking, pivoting;*

c) *Study of the form of the progression of the physico-chemical phenomena since the formation of undulatory wear began;*

d) *Influence of corrosion on the formation of undulatory wear;*

e) *Incidence of the deformation and wear of the tyres on undulatory wear. Beneficial effects of grinding the tyres.*

Summary of the replies :

a) Influences due to the operating, slipping and rubbing, chattering, torsional oscillations of the axles, etc. and those inherent in the materials of the rails and tyres, physico-chemical characteristics, oxydation by rubbing, work hardening, deformability, either overlap or are interdependent. Rails with undulatory wear are harder, have a higher elastic limit, and smaller elongation than rails free from such wear. (The influence of the elastic limit is not always definitely definable). It does not appear possible to affect the wear by adopting a greater radius of camber; the traffic ends by making a natural curvature of the running surface which it is almost impossible to alter.

In the preceeding paragraphs, we have already collected various observations concerning the subject proposed

under this heading, but all these data are not sufficient to help us in ascertaining the theoretical causes of the processus of undulatory wear of rails.

There are several theories to explain this phenomenon, but it remains to check their exactitude, and it would be better to consider the problem after we have finished summing up the remaining replies to the questionnaire.

b) No special observations in any way different from those already made concerning braking, skidding, etc. On the Rhaetian Railways, it has been observed that on a D.C. line, the rail motor coaches with electric brakes acting on the rail did not cause undulatory wear.

c) On a D.B. line, where rails of various compositions were laid one after the other, on certain days when the air was very humid, it was noted that after a train had passed the rails were covered with a film of oxide. The small amount of undulatory wear which followed afterwards disappeared to some extent. It was not possible however to find any definite relation between this undulatory wear and the formation of a film of oxide.

In Paragraph I. — 6), we have already quoted certain observations on the form of evolution of undulatory wear as time goes on.

d) Corrosion appears only to have a fortuitous influence, by increasing the depth of the depressions which are not touched by the wheels.

e) Short undulatory wear has been noticed on the tyres of certain locomotives.

V. Effects of undulatory wear on the track, bridges and viaducts, and the rolling stock.

V. — 1) *Has your experience enabled you to state that undulatory wear leads to :*

a) *the loosening and wear of the rail spikes, rail anchors, fishplates and fish plates bolts and base plates;*

b) *the wear of the sleepers;*

c) *the loosening of the nuts, the bolts fastening the transoms to the stringers of bridges and/or the breaking of these bolts;*

d) *the failure of rivets and bolts in the connections between stringers and cross girders and between cross girders and main girders of bridge;*

e) *wear of the pins and plates of the bridge bearings;*

f) *the loosening of the holding down bolts and the destruction of the mortar between the base of the bearings and the piers;*

g) *damage to the piers and abutments;*

h) *fatigue failures of the stringers, cross girders, main structure and bracing of bridges;*

i) *damage to the invert of tunnels or to the drains.*

Summary of the replies :

a) Nearly all the Administrations who replied to this question have found that on lines where there is intense undulatory wear, there is rapid deterioration of the line in general; the fastenings, coachscrews and bolts, become loose, the anticreep devices are removed, the bed of the sleepers and ballast upset, etc. The level of the track rapidly becomes deformed. On the S.N.C.F., it has been noticed that 3 months after a general overhaul of certain zones with undulatory wear, 30 to 50 % of the coachscrews were loose. On the Danish Railways, a line with very pronounced long wave undulatory wear had to be tamped once a week. On the Belgian Railways, the coachscrew holes have been found to

have got out of round, but no loosening of the GEO type fastenings with elastic fastenings has been noticed.

On the D.B., the influence on the bearing plates is noticeable when damping out poplar plates are not used. In general, it is found that the vibrations which occur with rails having undulatory wear have bad effects upon the fastening of the rails to the sleepers and on the general adjustment of the track. Rapid loosening of the ballast is noted even when the amplitude of the wear is not yet excessive.

b) More rapid deterioration of the sleepers has been noted in zones with marked undulatory wear, which become cut into abnormally; on the D.B., the life of sleepers in zones with undulatory wear is 4 years less compared with zones where the rails are free from such wear.

c) The S.N.C.F., D.B. and some other Administrations have found that on metal bridges the fastening bolts of the longitudinal sleepers between the cross stays and screws rapidly become loose; the bolts also break sometimes, but not very often.

d) Breaks of this sort are seen, but cannot be attributed with certainty to undulatory wear.

e, f, g, h, i) No incident has been noted to date which can be attributed solely to undulatory wear, with the exception of a certain amount of damage to the paving and roadways adjoining the lines, especially on urban systems.

V. — 2) Effects upon the rolling stock :

a) *Sympathetic corrugations in the tyres of the wheels;*
b) *Increase in the wear of the axle bearings, journals, axle guards, springs, etc.;*
c) *fatigue and breaking of springs and brake rigging;*
d) *loosening of the tyres;*
e) *loosening of white metal bearings;*

V. — 3) *Have you found it possible to estimate the cost of the damage caused to the rolling stock by undulatory wear of the rails?*

If so, does the extent of the damage bear any relation to the degree of undulatory wear? (Such an estimate would be of the greatest importance in deciding the expenditure that would be justified to prevent it or the cost of the measures taken to remedy undulatory wear).

Summary of the replies :

V. — 2) *a, b, c, d, e*) It is agreed in nearly all the replies that it is very probable that the wear of the components of the rolling stock, tyres, axle supports, journals, guard plates, springs, brake rigging, etc. is augmented by undulatory wear of the rails. On the other hand, the conservation of the rolling stock is improved by proper maintenance of the track and the adoption of long welded rails. Consequently, it is difficult to be precise on these points, seeing that the effects of undulatory wear on the rolling stock are difficult to isolate. The cases of breaks imputable to undulatory wear are very rare, and, on the other hand, no systematic information is available concerning the fatigue and breaking of rolling stock components.

In the U.S.S.R. the harmful influence of undulatory wear on electric rolling stock has been noticed in certain isolated cases, especially on the wheel drums, sand pipes, drum bolts, auxiliary poles, motor supports and motor brush-holders. On the Belgian National Light Railways and Rhaetian Railways, it is reported that the serious undulatory wear noticed may be the cause of broken axles on motor units, abnormal wear of the tyres and dislocation of the assembly of the carrying bearings of the motors.

V. — 3) No estimate has been made of the cost of the damage to the rolling stock. Such an estimate would appear to be difficult to make, as all the trains run over lines parts of which have undulatory wear and parts of which are free from it; in addition, other defects than undulatory wear, slipping, flaking, clips, defective level, etc. are also capable of causing equal damage, which it is impossible to isolate.

As for the damage caused to the permanent way, the D.B. estimates that this amounts to 20 million D. Marks per annum. Generally, all the Administrations who suffer from much undulatory wear make use of grinding to eliminate its effects, considering such a step economically justifiable.

VI. Measures taken to avoid undulatory wear or to remedy it.

Have any of the following measures been taken, and if so, with what results?

a) *Taking up rails with serious undulatory wear from straight sections or flat curves and relaying them on sharp curves, where normally undulatory wear does not occur?*

b) *Inserting a rubber pad between the foot of the rail and the sleeper bearing plate or between the bearing plate and the sleeper or transom?*

c) *The use of elastic fastenings to attach the rails to the sleepers?*

d) *Reduction or increase of the number of sleepers per rail?*

e) *Has grinding been used to remove undulatory wear, and if so, with what results?*

f) *Have the rails been heat treated, either before or after undulatory wear, and if so, with what results?*

g) *Any other measures?*

h) *The use of paints and protive coatings against corrosion;*

i) *Methods of grinding the rails in the shops or on the track by the use of special vehicles;*

j) *Cleaning the running surface of the rails with metal brushes mounted on locomotives;*

k) *Trials of grinding the rails before laying them to eliminate any undulations that may already exist.*

l) *Periodical rectification of the tyres by grinding.*

Summary of the replies :

a) The D.B. has already several times taken up rails on straight sections with serious undulatory wear and laid them on curves of small radius. The existing undulatory wear was ground out by the transversal slipping of the wheels, especially on the inner line of rails. On the Belgian Railways, similar trials have been made but too recently for decisive results to be given.

b, c) The Administrations who have made observations in this connection (Belgian, Danish, Dutch, Rhaetian, Swiss, D.B., S.N.C.F., R.E.N.F.E.) have found that the use of elastic type fastenings with rubber bearing plates has not led to the disappearance or reduction of undulatory wear with either long or short waves. No type of fastening can prevent undulatory wear, which is essentially a function of the nature of the metal. Of the new rails laid between 1951 and 1953 on the S.N.C.F., 11 % of those laid with ordinary fastenings and 9 % of those laid with elastic type fastenings had been attacked by undulatory wear by 1956. Studies and trials, however, show the value of having elastic components in the fastening, intended either to protect the supporting area of the sleepers or the coachscrew holes, or to compensate the

play caused by the wear of the fastenings and put a brake on the processus of dislocation. In addition, it remains to learn whether the evolution of the phenomenon of undulatory wear can be favourably affected thereby, since the introduction of elastic components in the fastenings is relatively recent.

d) Increasing the number of sleepers has a certain beneficial effect as regards long undulatory wear, but has no effect in the case of short undulatory wear, according to the observations of nearly all the Administrations. In trials on a section of line with sleepers spaced at 55, 65 and 75 cm (D.B.), no difference at all was noticed. Other trials on the Belgian Railways also gave equally negative results.

e, i) On the D.B., for the last 4 years, existing undulatory wear in the track has been removed mechanically :

1) By planing 1.2 mm when held down rigidly, the reconditioned rails before relaying them. This operation is done on more than 100 000 m per annum, at the Hamburg-Harburg Permanent Way depot, and in two private factories. Cost approximately 700 DM per kilometre of line.

   At Nuremberg Depot, there is a grinding installation for « DISKUS » type rails in which reconditioned rails can be ground. Cost approx. : 1 700 DM per kilometre of line.

2) To grind the rails on the permanent way, there are small mobile « Rixen » grinders with electric or petrol engines. 10 to 30 passes must be made to remove an average degree of wear. Cost approx. : 600 DM per kilometre of line.

3) In 1952, a special grinding rake was built by « Krupp » with three vehicles each with 8 grinders turning around a horizontal axis. At a speed of 3 km/h this removed about 0.28 to 0.30 mm of metal. Annual output about 2 500 km. Approximate cost : 216 DM per kilometre of line.

4) Use is also made of « Schörling » grinding vehicles equipped with rectangular grinders applied hydraulically against the rails. Four coupled vehicles each having 4 grinders on each side, running at a speed of 25 km/h remove about 0.04 mm, of metal as they pass. 5 runs remove the undulatory wear from 1 km of line. Cost : 110 DM.

These measures in conjunction with renewal of old rails has made it possible to get 80 to 90 % of the main lines free from undulatory wear.

On the S.N.C.F., the « Scheuchzer » wagon with abrasive skids is used. 40 to 60 runs are usually sufficient. The wagon has two sets of 4 skids per line of rails, consisting of magnesian agglomerates. The pressure is given by a cylinder using compressed air.

In the shops, to remove long wave wear, automatic grinders are used as the amount of metal to be removed is small. In the case of short undulatory wear, a technique has been perfected consisting of planing on a machine tool with a long table, which gives rapid and economic results. Trials of straightening in a press were found ineffective.

In the U.S.S.R., since 1949, the rails have been polished on urban lines by means of special wagons. No other measures have been considered to date.

Since 1950, the Swiss C.F.F. have ground rails with undulatory wear, first of all by means of hand operated machines, then with wagons with grinding skids. From 1954 to 1957, 1 450 km of main lines were ground. Cost 80 cts. per metre of line, i.e. 1.5 % of the cost of the rails. The grinding is carried out at the same time as the general overhaul of the track. The quality of the running surface after grinding is often better than that of a new rail. In addition, there is a considerable

improvement in the running surface in line with the joints. At the present time, no grinding is done in the shops.

On the Rhaetian Railways for the last two years, a Matisa grinding wagon has been used having a speed of 25 km/h. Average cost 44 Fr. per metre of line.

On the Danish Railways, short undulatory wear is ground out only since 1956. Long undulatory wear has been ground out since 1951, it being necessary to grind the track every 2 to 3 years.

To remove long undulatory wear at a given point, a « Rixen » apparatus is used mounted on two wheels, and pushed along the rail by one man. To grind long undulatory wear a « Krupp » vehicle is used hauled by a trolley, on which is fitted the generating set supplying the power for the grinding motors. To grind both long and short undulatory wear a « Scheuchzer » wagon has been available since 1956.

On the Belgian National Light Railways, two types of vehicles are used. One of them has abrasive skids, the other rotating grinders. It has been found very difficult to compare the results. A grinding truck drawn by a motor unit has also given good results.

On the Netherlands Railways, grinding is done by means of special vehicles, and also on the Paris Transport Boards (R.A.T.P.), who grind about every 18 months in order to avoid the accentuation of undulatory wear.

f) On the D.B., reheating the rails has not been very successful. Annealing the rails at 850° in a furnace before laying them had better results. The heat treated rails being more susceptible to undulatory wear than the ordinary rails, trials have been made on the S.N.C.F. of annealing the top of the railhead by flame and by high frequency heating in order to destroy the work hardened layer of the crests. The results are uncertain and the cost was found to be higher than that of grinding.

On the R.A.T.P., some trials have been made with martensitic rails laid in place of sorbitic rails. Undulatory wear appeared after a much longer time (6 years instead of 1), but these trials were not continued. The Belgian Light Railways (S.N.C.V.) and S.N.C.B. have made trials of heat treatment before laying and annealing afterwards on site but without any results.

g) On the D.B., trials have been made of cross stayed sleepers with negative results. On the S.N.C.F., endeavours have been made to act upon the characteristics of the steel by limiting the proportion of carbon and resistance to traction. It is systematically made certain that the rails do not show any undulations when leaving the manufacturer's works.

j) Trials of cleaning the rails made by the D.B. with a hand brush have proved that undulatory wear can be prevented by daily brushing, but this does not appear to be economic.

k) Wear occurs after a longer period on rails that have been planed before laying, but afterwards continues to increase (D.B.). Grinding new rails before laying them has recently been tried (D.B., S.N.C.F.) but the results are not yet known and the profitability of this method remains to be proved. Trials of grinding shortly after laying have given good results on the Belgian National Light Railways.

l) Grinding the tyres costs too much and only trials have been made. The tyres are generally reprofiled by forming and turning.

VII. Results of systematic research work.

a) *On trial sections, giving the various arrangements made and the material and rolling stock used;*

b) *In the laboratory by causing undulatory wear on test rails.*

Summary of the replies :

a) On the D.B., on a line built for test purposes in connection with undulatory wear, in 1951, different types of rail were laid, from various rolling mills and fabricated by different processes :

1) normal Thomas steel rails;
2) Thomas steel rails with additional manganese;
3) normal Thomas rail elaborated with an oxygen rich blast;
4) normal Martin-Siemens steel rails;
5) Martin-Siemens steel rails with additional manganese.

The rails of each of these categories were varied by the use of the following treatments (110 combinations) :

a) usual straighthening in roller type straightening machines;

b) straightening in hand press;

c) excessive straigthening with the roller straightening machine;

d) normal straightening then annealed 850° in the furnace and again straightened, this time by the hand-operated press;

e) usual straigthening by the roller machine, then planing off 2 to 3 mm.

The results obtained showed that :

1) Certain rails, especially amongst those made of Thomas steel, showed pronounced undulatory wear, whilst the rails made of Martin-Siemens steel, all of which had a low nitrogen content, remained exempt or at the most, only slightly affected by small systems of wear.
2) The influence of increased stressing of the rails by the roller straightening machine produced the original undulatory wear.
3) The comportment of rails made of Thomas steel elaborated with oxygen blast was similar to that of the Martin-Siemens rails.
4) The comportment of the annealed rails was also favourable. The detailed analysis of the information collected is still being made however.

Two trial sections were laid in 1951, on the S.N.C.F., on lines with different types of traffic, in zones which had always shown intense short wave undulatory wear. Variations were made in the metallurgical factor and the mechanical factor.

Metallurgical factor. — Two different profiles of rails were laid : *a*) in low nitrogen content Thomas steel; *b*) in soft average and hard Thomas steel; *c*) in sorbitic heat treated steel; *d*) in martensitic heat treated steel; *e*) in heat treated steel preliminarily annealed.

Mechanical factor. — One trial section was welded throughout, the other laid with the usual joints. All the different types of rails were laid on each section : on wood sleepers with bearing plates; with elastic fastenings and rubber plates; on concrete sleepers.

In addition 4 rails that had been given artificial undulatory wear over half their length, either by pressing or by grinding, were laid.

Results. — The method of laying plays very little part in the tendency toward undulatory wear, but the chemical composition, heat treatment and method of fabrication of the rails have an essential influence. The soft and average rails and the rails with a low nitrogen content are exempt from undulatory wear. The hard rails and heat treated martensitic rails show traces of incipient undulatory wear. The heat treated sorbitic or half-annealed rails show characteristic undulatory wear. The artificial undulatory wear given to 4 rails of ordinary average steel disappeared. The surfaces of the ordinary rails are without defects whereas those of the heat treated rails seem to be on the verge of flaking.

On the Swiss C.F.F., in 1956, a sec-

tion of track was laid with rails from three different steelworks, elaborated according to different processes, and made of two qualities of steel, but in spite of a traffic of 23 000 gross t per day, these still show no signs of undulatory wear. In the U.S.S.R., research has shown the preponderant influence of the original deformations in the rails in the development of undulatory wear after they have been laid in the track.

b) Undulatory wear has been reproduced under laboratory conditions by rubbing a rail with steel bars, and also by the rollers of an Amsler wear test machine. The D.B. have endeavoured to influence the torsion oscillations by creating artificially a difference of 4 mm in the dia. of two wheels on a single axle. The smaller dia. wheel showed clear signs of undulatory wear on its tyre, with a wave length of 2.8 cm, which seems to indicate that the chatter plays some part. All these trials are not yet completed.

VIII. Measuring and recording equipment.

a) *of undulatory wear;*

b) *to determine the elastic stresses in the rails;*

c) *description of the equipment and methods used.*

Summary of the replies :

a, c) Profilographs are used which record on a scale of 20/1 the amplitude and length in natural size; equipment to draw the waves of undulatory wear fitted on special vehicles; Neuweller and Matisa rulers with large vertical amplification; Solex equipment; the wear is also translated into graphs showing the condition of the line made by means of the equipment on the measuring wagons.

b, c) To measure the elastic stresses the « Elastomat » is used which operates by excitation of vibrations, by coupling through reaction, on a test model, the measure of the actual frequency of which makes it possible to determine its modulus of elasticity. These measurements are also made by means of gauges with resistance wires; by strain gauges; by special crack development varnishes; by accelerometers; or by photoelasticimetry.

C. CONCLUSIONS.

We are going to recapitulate the information received concerning the conditions in which undulatory wear of the rails occurs and the experiments made in connection therewith, and we will endeavour to establish at the same time some summaries relating the above mentioned data with the explanations given about this phenomenon by the various theorists who have studied the question.

Concerning the kinds of undulatory wear, the different types noticed may be considered as belonging to one or other of the two big classical divisions :

a) Short wave undulatory wear. Most frequent length 4.3 cm. Polished crests and dull depressions. Appears sometimes soon after laying and tends to arrive at a certain degree of stabilisation. Generally seen on straight sections and wide curves.

b) Long wave undulatory wear. Lengths 20 to 200 cm. Crests and depressions both look much alike. This wear often appears immediately after laying and increases with the age of the rail as imperfections in laying become accentuated. This wear is found above all on lines run over by homogeneous stock running at frequent intervals at a uniform speed, whereas short wave undulatory wear is a condition of main lines.

There is also short wave undulatory wear in the braking areas and on curves of small radius. The first is probably due

to the phenomenon of chatter in relation with the elasticity of the suspension and the variation in the coefficient of friction between rail and wheel when the wheel slides over the rail at varying speeds. The second appears to be due to the fact that the conicity of the tyres cannot compensate the difference in development of the two lines of rails, which causes a periodic succession of rolling and slipping on the outer rail, probably in relation with the elastic torsions and relaxations of the axle.

Undulatory wear or rather deformation on straight sections of the open track, whether long wave or short, seems harder to explain theoretically. The factors, which come into play, seem to be extremely numerous, both as regards the influence of the constituents of the track and the influence of outside factors. This type of wear presents at one and the same time the most complex theoretical problem and the most important practical problem, as it is the most extensive and harmful form.

Undulatory wear summarily characterised in this way in reality has variable aspects which in many cases are lacking in concordance, in the two categories reported. For example, on the main lines of the U.S.S.R., there is no short wave undulatory wear, but this has been observed on the tramway lines. Undulatory wear having small waves with polished crests and depressions has been found on the S.N.C.B. No statistics of the comparative extension of the various types of wear observed have been got out, but generally the type with short waves is the most widely found on the main lines as well as being the most harmful. The most numerous experiments have been made with this type of wear, but so far with little result in ascertaining the causes.

On the other hand, the theories advanced to explain the resultant phenomena are as diverse as uncertain. They are not only diverse but also show partiality. All complex problems treated theoretically lose contact with reality, as being unable to contain in all their ampleur the hypotheses selected, somewhat according to the subjective selection of the theorist, from which he proceeds to reconstruct the facts imaginatively. Thic reconstruction however is lacking in essentials so cannot be an explanation of what really is the cause.

The variety of the opnions held by the theorists can however be reduced by grouping together those which only show slight differences. This enables a brief resumé to be established :

1. *Hypotheses which attribute the formation of undulatory wear to the material used for the rails and the method of fabricating them.*

Too great differences in the pressure undergone whilst passing through the rolling mill and being passed through too many times (THONET). The size of the ingot can be the cause of different working during rolling (NEVWEILER, FLÖTER). Too high a temperature during the last passage through the mill (POTIN). Vibrations when coming out of the rolling mill (PERROUD). Lack of homogeneity of the material and defects in rolling (BUSSEL). Slipping on the rollers when passing through the straightening machine (SALLER). Irregular cooling (STÖCKER). Undulating form of the zone of segregation by wiredrawing in the blooms, by the rolling, and by the wear of the rollers. Unequal resistance to corrosion and mechanical wear of the segregated and non-segregated zones (DRESSLER). Excessive proportion of manganese (MOYLE). Original undulations accentuated after laying (KUHNER) (TAYLOR). Defects in the rolling mills and straightening machines (BIANCHEDI).

2. *Pressure and rail-wheel movement.*

Plastic deformation of the rail (rolling out and upsetting) through the action of the loads which stress it beyond the elastic limit at the point of contact between wheel and rail. The rail seat forms an anvil. The metal driven out forms a flange which

becomes very hard. The wheel hits against this, gets over it and falls back on the rail, and so on. The interval between the waves is a function of the malleability of the rail. The vibrations and shocks are considered to be secondary effects (GIDANSKI) (BEAUMONT) (PELLISIER) (DELCROIX).

3. *Vibration of the rail.*

If the rail is vibrating rapidly, the pressure and degree of adhesion at the point of contact undergo variations proportional to the amplitude of the vibrations and of the same frequency. The tangential force at the point of contact remaining constant, the variations in adhesion can be translated by periodic accelerations and decelerations in the speed of the wheel, and as the mass of the vehicle cannot follow these, there must necessarily be a succession of skids. Wear is caused through the abrasion and crushing of the rail by the skids and shocks from the wheels. That is to say : periodic variation in the regime of the rail-wheel pressure, with correlation of the vibrations of the rail and oscillations of the vehicle (WILKINSON) (FRÉMONT) (DUBS) (MEYER) (SPADERNA).

4. *Vibration depending upon the original internal stresses of the rail.*

The tension inside the head of the rail determines the frequence of the vibration of each rail. The vibration in the body of the rail reduces the friction and the wear is greater in the centres. The internal stresses start during the straightening in the rolling machine (KRABBENDAM).

5. *Reactions of the rail-wheel system with the influence of the rolling stock.*

Resonance between the vibrations of the wheels and the rails through the influence of the non-suspended masses. Chemical transformations due to the raising of the temperature in the rail-wheel contact area (MONET-PALMÉ). Influence of the vibrations of the axle and not of the rail (RICHTER). Influence of the chemical quality of the material of the wheels (PUPPE). Of the distribution of the material in the wheels (BASELER). Influence of the non-suspended masses (KOFFMAN). The dynamic behaviour of the vehicles in relation to the rails (SCHWENN). Influence of the tipping movement of bogies when the brakes are applied; the long waves in particular are in relation with the stock (SCHEIBE). Oscillations of the horizontal sliding of the axles (RÉSAL). The rail-wheel slide undergoes fluctuations of the same frequence as the periodic vibrations of the load, linked up with certain types of the elastic deformation of the whole of the non-suspended masses and the track. The rail becomes deformed and fixes the wear by exceeding the elastic limit on the influence of the dynamic overload. The length of the wave is a function of the vibratory characteristics of the axles. The abrasion is the cause of the undulations, the depressions wearing more than the crests (CHARTET).

6. *Influence of the oxidation caused by friction.*

Oxidation of the surface of the rails under the action of the plastic reformations and the chemical activity which favours it; in the processus of rhythmic oscillations of friction (sliding and rolling), by exceeding the maximum coefficient of adhesive friction. The slipping drives off the products (crests) and the rolling crushes them (depressions). The driving wheels, with high moments of rotation, favour this phenomenon. The vibrations are not the cause but the effects of the preliminary undulations (FINK). Corrosion attacking by friction (TERRIS) (DEARDEN). Corrosion combined with the rhythmic rebounding of the wheels which rub on the rail, remove the humidity, and heat it and harden it through the shocks. The spot where the wheel rebounds again the running surface remains humid and

continues to corrode. Influence of the torsion of the axles and the driving and carrying wheels, which speed up and slow down during these rebounds (Sieber) (Vichert) (Turner).

Resumé of the remedies suggested by the theorists.

Rails having a soft-ductile nature resistant to crushing, rich in factors capable of raising the points of transformation of the steel and less rich in tempering agents; resistant to corrosion or with formation of a film with a low coefficient of friction; high limit of elasticity. No agreement on the moment of inertia. Flexible formation, elastic bed, sleepers with elastic return, hard sleepers so that the rail will vibrate independently of its bed. Planing the surface of the rails before laying them. Controlled cooling to reduce the internal traction stresses in the rail head, owing to the more rapid shrinkage of the web. Reduction of the conicity of the tyres and in the play between the flanges and rails. Sweeping away the products of oxidation. Use of anticorrosive chemical solutions to water the rails. Non-metallic brake shoes. Modification of the characteristics which give rise to rail-wheel synchronised vibration. Use of devices to absorb the shocks, especially in the driving wheels. Reduction in the weight of the non-suspended masses, etc.

All these explanations, putting the accent on one or other factor in order to justifify the processus given for undulatory wear, give but little satisfaction to the enquiring mind. In addition, it is very difficult to unravel the true order of concurrent causes and decide which factors first come into play and damp out the effects of the others. For example, opinions are still divided as to whether the vibrations of primordial importance are those of the rails or those of the axles, or neither the one nor the other but both playing a secondary role. From the practical point of view, subjective preference concerning the order of the causes is of little importance. All the factors which have a harmful effect should be considered equally from the point of view of the facility or difficulty of attacking them with effective measures to diminish this harm.

Let us examine first of all the result of the replies received to the present questionnaire. There are certain experiments on the consequences of which all the Administrations are more or less agreed. In addition, systematic proofs have been obtained on some Railways. But the résumé of the results is still very incomplete, seeing that the trials have been too recent for the final conclusions to be deduced.

From all the influences, which play a part in undulatory wear, characteristics of the rails and the method of their fabrication, their laying and the nature of the roadbed, the traffic and the rolling stock, it can be considered as proved that the most important and necessary for its development resides in the rail itself. In the metal of which the rail is made, there is a predisposition which plays an essential part in the apparition and development of undulatory wear. The influences due to the method of laying play a less important role than the actual nature of the rail. These influences (type of sleeper, fastenings, welding the joints, bed and formation) can contribute to slowing down more or less the evolution of the defect, but by themselves cannot produce it on any rail. There is a similar characteristic in the case of the influence of the rolling stock : pressure and stresses from the wheels, dynamic stresses depending upon the suspension and damping out devices, effect of the non-suspended masses, making possible a harmful coupling between the vertical and transversal vibrations of the axles, uniformity or diversity of the traffic, etc.; all these influences develop undulatory wear, but they are not capable of producing it on all types of rails; only those rails that are predisposed to it are attacked.

From the point of view of a complete explanation of the formation of undulatory wear, the verifications made are insufficient. The phenomenon occurs as a function of the predisposition of the rail through the dynamic effect of the loads, favoured perhaps by defects in the elasticity of the permanent way, but the technique of the periodic processus which comes into play has not yet been clearly ascertained.

It is difficult to evolve any explanation even of the particular or local aspects of the phenomenon. For example, the machine used to straighten the rails with rollers is the only equipment in the processus of fabrication which does not work upon the end of the rails, a fact which can be related to the observation that when rails are affected by undulatory wear this often spares the ends. But it is also possible to think that there may be some modification in the dynamic effects of the loads through the variation in laying the rail caused by the joint. Light rails are less affected by short wave undulatory wear than heavy rails, but the hardness and nature of the metal, the characteristics of the traffic, etc. may also have an influence on the observations made with rails of different weights. The influence of electrification on the development of undulatory wear has been noted, but the increase in the axle loads and speed which it brings with it must also be remembered. Generally, every observation made may be linked up with some other possible influence.

There are also circumstantial effects which may have a well defined local cause. On level crossings, undulatory wear fades out, a fact which may be explained by the presence of the check-rails which damp out the vibrations of the rails. Undulatory wear is seen to be greater on lines over which empty stock is frequently run, a fact which may be due to the lesser effect of the friction of the wheels on the crests, which in the case of loaded stock can produce a mechanical grinding effect.

To conclude, it is in the rail where the fault occurs that the most essential part of the causes resides, but in spite of the experiments made it has not yet been possible to select a type of rail which possesses a real guarantee of immunity to undulatory wear. The practical remedy for the time being is to grind the running surface when the wear exceeds 0.2 mm and becomes harmful for the fixed installations and rolling stock, as well as the comfort of passengers. In addition, grinding is profitable, seeing that it costs less than the damage it prevents, even if the damage caused to the track is not taken into account.

[656 .223 .2]

The allocation of empty wagons by the application of operational research,

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I. Introduction.

We do not know if it is still necessary, when dealing with a case of operational research, to begin by explaining what is meant by this research. In recent times, its use has been extended in such a way and so much has been written about it and its various applications, that we doubt if there are still many technical experts who have not come across it or have not at least an idea what it is and what methods it makes use of. We do not think therefore that there is much point in dwelling on this initial fact and it will be sufficient to recall very rapidly some of the essential ideas. Operational research, to give a very general but concise definition, is the *application of scientific methods in the analysis of activities which concern the management of undertakings*. It is one of the branches at the present time of the scientific management of undertakings, known in English as « scientific management » which by the application of an unlimited number of scientific methods, has as its object the study of problems in connection with the management, i.e. those which affect an organisation or undertaking as a whole amongst which there is interaction of effects. The object of this research is to supply the management with quantitative bases for the decisions it has to make in situations where there is a choice between various alternatives. The scientific methods used are very varied; they may make use of different theories or mathematical models; frequently mathematical statistics are used, and in every case the analysis is based on the observation of the processus, operations or activities under actual conditions and in their dynamic evolution; any variations must be confronted with the reality. This very important characteristic of this research, which is made under « operational » conditions has been picked out and is incorporated into the name under which it is known in the different countries, for example in its French name, which we are using here, because it is the term generally used — though let us state here with some doubt as to whether it is altogether the right term. We would prefer some name which gave a better translation of the American term « Operations Research » rather than the English « Operational Research ».

As has been said many times in numerous articles and descriptions of this research, it was born during the world war, by developing various methods

which it has now made its own, getting organised and working very succesfully by the first groups of scientists who applied their habits of observation and scientific criteria to the study of the operations of war, first of all in England and then in the other Allied armies in their various branches.

In the post-war period, the same methods began to be applied to peacetime activities and industry, chiefly and first of all in the United States. In this latter country, they have reached a high level of development, both as regards the scientifico-theoretical aspect and the practical application to the extensive field of industry. Amongst this latter, that of the railways was not one of the first to be dealt with, as this method has not yet been adopted in the degree and to the general extent corresponding to the importance of railway undertakings and the usefulness of the research.

But since studies of this operational research began to be made on some railways, by groups of research workers specialising in this field, and on others by private consultants as well as by university organisations working to this end, they have developed fairly rapidly and in the last few years, interest in them has grown as well as preoccupation with the role which should be attributed to them by the Railway Companies. The post 1954 bibliographical references which we quote [1] to [8] (*) give a picture of this recent development of Operational Research on the American railways, together with details of the cases in which it has been applied. In this latter connection, the information can be completed by reading articles [9], [10] and [11], the first two of which describe the work done in the application of Operational Research in British transport.

Amongst the mathematical methods used by Operational Research is *linear programming*, of which we are now going to give some idea, in which the *problem of transport or Hitchcock's problem* is a simple particular case with which we are going to deal. The distribution of excess wagons to different points amongst a great many others where they are needed in certain quantities, so that the total transport cost is the lowest possible, is a direct application of this latter problem. The distribution of empty wagons is a permanent daily operation on all railways, and its cost is important. For example, on the Spanish Railways, where the mileage of empty wagons represents 26 % of the total wagon mileage, the cost of transporting them is of the order of 1 000 million pesetas. A possible saving of 10 % would give an annual saving of the order of a hundred millions. It is therefore natural that such an application should appear to the specialists in Operational Research as one of the easiest and most urgent for the railways, together with other equally obvious ones, such as a study of the functionning of marshalling yards by the theory of « queues »; that of the renewal of rail and material by the theory of replacement; that of the control of receipts by « sampling » and others which are also of great importance.

In particular, the problem of the

(*) See *Bibliography* at end of article.

distribution of empty wagons has already been the subject of various articles in the technical press for some years (see ref.: [12], [13] and [14] and it is such a simple application of the transport problem that it is commonly used as an example to explain this problem as is done in articles [15] and [16]; this latter article is perhaps the first which recapitulates in a systematic manner the methods of Operational Research most often used in industry.

As we will see later on in the practical application of the solution to the problem, when certain complications arise, recourse to electronic computators is necessary. There is thus a combination of the value for the railways of the use of this scientific method by which this aspect of its working may be improved economically, with that of successfully solving it by using modern computators. These, with their great working capacity, must be used for the working out of a large number of operations which as a whole will make it possible, whilst rationalising administrative methods, to obtain the greatest possible economy, which will make up for and indeed turn into a profit the high cost involved in using such computators. The desire of the railway companies to make use of computators in their departments for rationalising and simplifying their administration involves a preliminary study of all the operations and all the methods to be covered by them, and this is certainly a problem for Operational Research to find a general programme for such an application. Incidentally, we might say that as far as we know, such an investigation has already been carried out by the « Chesapeake and Ohio Railroad » when in the spring of last year it installed a UNIVAC in its central offices at Cleveland, and in references [17] and [18], it is question for the first time of the application of computators to the distribution of empty wagons on the « Southern Pacific » in an operational research undertaken by the « Stanford Research Institute » which was also the subject of one of the discussions at the spring 1955 meeting of the « Railway Systems and Procedures Association ». The application of computators to Operational Research in general has been dealt with in [19] and [20] in the French technical press.

In the present study, we propose to deal with the solution of the problem of the distribution of empty wagons by the application of this kind of Operational Research which is known as the transport problem. For this purpose, we will explain the theoretical development of the problem in basic cases so that without going too deep into the mathematical aspect, it is possible to understand the theoretical foundation sufficiently to appreciate the technique of the solution; we will then deal with various points in connection with the complications which may occur in the application of the method.

II. Solution of the problem in a simple basic case.

Right from the start, we will deal with a concrete case with data which occur in reality on a given railway. We will suppose that on this railway, at the end of a working day, we known the number

of wagons of a certain category which are still empty and available in each of seven yards, localities or regions, as well as the number of wagons of the same category which will be needed the next day at the same seven points, and that we know also the cost of transport for an empty wagon from each of these centres or regions to each of the others. It goes without saying that an accurate knowledge of this group of data is another problem to be solved, but for the moment, we will take it that these factors are known. We will also accept the supposition that the transport from one point to another takes place in a given time, that all the wagons consigned can reach no matter which destination in time to be used during the day they are needed. And we will also take it that the cost of transport of the wagons does not vary with their number, i.e. the unit cost remains constant for a given journey. In our first simplification, we also will take it that the number of wagons which remain available in some yards is equal to the total number short in the others.

For example, taking a railway with seven zones or regions, which we will designate by A, B, C, D, E, F, and G. The surplus and shortage of empty wagons, designated by the signs + and — after calculating local requirements, is as follows :

$$\left.\begin{array}{ll} A & +\ 25 \\ B & +\ 75 \\ C & -\ 10 \\ D & -\ 75 \\ E & +\ 50 \\ F & -\ 90 \\ G & +\ 25 \end{array}\right\} \quad (1)$$

and the cost of transporting a wagon from each of these zones to another is as shown in the following table 2 :

	A	B	C	D	E	F	G
A	0						
B	7	0					
C	13	8	0				
D	10	10	15	0			
E	14	14	23	7	0		
F	5	12	21	12	12	0	
G	8	11	20	15	22	10	0

(2)

The surplus wagons at A could be distributed in many ways between C, D and F, and in the same way, those of B, E and G. Using as first index figures 1, 2, 3 and 4 to designate wagons *coming from* A, B, E and G respectively and as second index figures 1, 2 and 3 to indicate the wagons *intended for* C, D and F respectively, in such a way that x_{23} is the number of wagons going from B to F, the conditions of the problem can be expressed analytically by the equations :

$$\left.\begin{array}{l} x_{11} + x_{12} + x_{13} = 25 \\ x_{21} + x_{22} + x_{23} = 75 \\ x_{31} + x_{32} + x_{33} = 50 \\ x_{41} + x_{42} + x_{43} = 25 \\ x_{11} + x_{21} + x_{31} + x_{41} = 10 \\ x_{12} + x_{22} + x_{32} + x_{42} = 75 \\ x_{13} + x_{23} + x_{33} + x_{43} = 90 \end{array}\right\} \quad (3)$$

But these seven equations are not independent, as any one of them is a linear function of the six others, as can easily be seen, since the sum of the first

four is identical with that of the three last. This leaves us with a system of six equations with twelve unknowns which allows of an infinite number of solutions. As the nature of the problem imposes the restriction that the solutions must be complete, positive numbers, the number of systems of solutions will not be infinite but there will be a great many. It is a question of determining for which one of them the system for which the value $13\ x_{11} + 10\ x_{12} + 5\ x_{13} + 8\ x_{21} + 10\ x_{22} + 12\ x_{23} + 23\ x_{31} + 7\ x_{32} + 12\ x_{33} + 20\ x_{41} + 15\ x_{42} + 10\ x_{42}$ is the lowest possible.

In algebraic notation, it is therefore necessary to find a system of complete solutions for the variables x_{ij} ($i = 1.2.3.4$; $j = 1.2.3$) which meet the conditions :

$$\left.\begin{aligned} \sum_j x_{ij} &= p_i \\ \sum_i x_{ij} &= q_j \\ x_{ij} &\geqslant 0 \end{aligned}\right\} \qquad (4)$$

and such that :

$$z = \sum_i \sum_j c_{ij}\ x_{ij} \qquad (5)$$

is a minimum.

This problem is only one particular case of the more general problem of the linear programming which can be expressed thus : find the system or systems of solutions of the equations :

$$\left.\begin{aligned} &\sum_j a_{ij}\ x_j = p_i, \\ &(i = 1.2, \ldots .. m;\ j = 1.2, \ldots n) \\ &\text{whence}\quad x_j \geqslant 0 \end{aligned}\right\} \qquad (6)$$

such that :

$$z = \sum_j c_j\ x_j \qquad (7)$$

is a maximum.

We will not go into the complete theory of the linear programming here, and we will merely indicate for the benefit of those who wish to know it that they will find it explained, together with its application to the problem of transport, in references [21], [22] and [23].

From the established terminology for the theory of the linear programming we will borrow the following terms. Is known as *applicable solution* any system of solution of x_{ij} which satisfies the equations and inequations of condition (6) or in the problem of the transport of the (4)'s. An *applicable solution* is *maximum* when it verifies in addition the condition of maximum (7) or the (5). A condition of minimum can be transformed into one of maximum by changing the signs of the coefficients c. It is shown in the linear programming that if a problem such as that set in (6) and (7) has maximum solutions, these are *basic solutions* or may derive from *basic solutions* as coordinates in a space to n dimensions grouping interior points of a convex body engendered by the said basic solutions. Are known as *basic solutions* those constituted by systems of the values of x in which $n - m$ of them are nil. In general, this is the greatest number of unknows which can take the value zero, as after the cancelling out in (6) of this number of unknown factors, there remains a given system in the first group of equations which, if it satisfies the second group of inequations will be a system of

applicable solutions. We will then show a verification of the suitability of the basic solutions in our own particular case.

Before doing so we will give the broad outlines of the simplex method, to solve the linear programming, which are similar to those we will follow in this case. These consist in determining a first basic applicable solution and checking whether it is or is not maximum; if it is not, another must be found, also basic, but better, i.e. closer to the maximum solution, and this processus must be continued as it is finite seeing that the number of basic solutions is finite. It must then be ascertained whether this is the only one or if there are others, find what they are, and, knowing all the basic solutions, derive from them all the maximum solutions.

We will develop this processus in our case by following the shortened method, the mathematical justification for which can be found in [22], making use of the results which we obtained from this abbreviated method in [24]. In this method, we begin by drawing up a table which we will call the table of solutions, on the lines of the table (8) in which we will put in the first column the stations that have wagons available, in the first

	C	D	F	
A	φ_{11}	φ_{12}	φ_{13}	25
B	φ_{21}	φ_{22}	φ_{23}	75
E	φ_{31}	φ_{32}	φ_{33}	50
G	φ_{41}	φ_{42}	φ_{43}	25
	10	75	90	

(8)

row those where wagons are required, in the last column the respective numbers of wagons remaining, and in the last row the number of wagons needed. With no matter which solution of the problem, it will be necessary to substitute for x_{ij} complete, positive numbers such that added up by rows and columns they give the sums shown in the last column and last line. To calculate the costs, we will put in another similar table (9) the costs taken from table (2) which may

	C	D	F
A	-13	-10	-5
B	-8	-10	-12
E	-23	-7	-12
G	-20	-15	-10

(9)

affect the problem. These costs are given with — signs for the problem to be converted into one of the maximum. A basic solution, in our case, must have six x nils from what we have already said. In general the number of lines being m and the number of columns n, the number of cases concerned in a basic solution must be $m + n - 1$. In [24] we show that for it to be so, the positions occupied in table (8) by x which are not nil must be such that taking the table as a chessboard, there can be no complete turn round movement. This condition is fulfilled, and with it, the solution found is a basic one and at the same time it is found to be applicable in the simplest manner by following the so called North-West (N.O.) rule. Thus we take the space in the top left hand corner

of the table (N.O.) and put as the corresponding value of x the lowest of the values in the row and last column, and in the first column and first row, i.e. 10. This means that 10 wagons are sent from A to C, when there will be no need to send any more to C and the three remaining spaces in column C will be zero. Let us go on to the next space in row A. We insert therein the greatest value between the difference still available at A and the wagons needed at D, i.e. 15. There are no longer any wagons in A and the space AF is occupied by a zero. We go on to the nearest N.O. space of those which remain, i.e. case BD; 15 wagons have been sent already from A to D and only 60 are needed; as 75 are available at B, we can send these 60 from B. Already spaces ED and GD are zero. Obviously we must complete the table by entering 15 at BF, 50 at EF and 25 at GF; we have then found a basic, applicable solution, but we do not know if it is minimum. We do not know if the cost resulting from $10 \times 13 + 15 \times 10 + 60 \times 10 + 15 \times 12 + 50 \times 12 + 25 \times 10 = 1910$ could be improved upon.

	C	D	F	
A	10	15		25
B		60	15	75
E			50	50
G			25	25
	10	75	90	

(10)

To check this, we can get out another solution, which is also basic and applicable. We can do so by using any other of the relations from a starting point or destination which have not been used in solution (10). These relations which are the six AF, BC, EC, ED, GC and GD, have one striking property which is that the space representing them in (10) closes a run, and one only in turn with the spaces occupied.

We are going to use a graphical representative to help us in explaining the running which we have drawn to prove the properties we are using. In figure 1a we have placed as on a map the 4 starting stations A, B, E and G which we have marked with the sign ◇ and the three destination stations C, D and F, marked with an ○ at relative distances corresponding more or less to

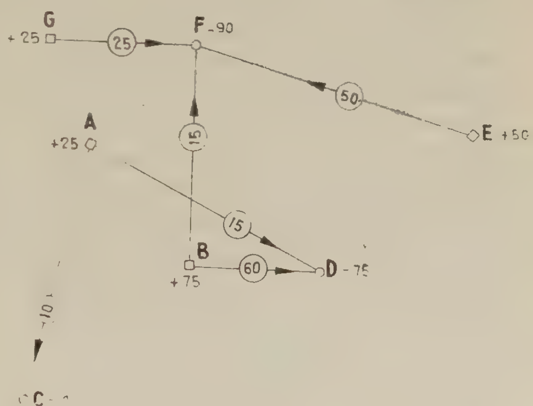


Fig. 1a.

the cost of transport. Beside the letter denoting each station we have put a figure for the number of wagons surplus or required. Let us join by a line the routes used in the initial basic solution found by the N.O. rule, and on each line indicate the number of wagons

running on this route and their direction. We see that the resultant broken line is not closed and does not include any closed portion, which corresponds to the property we mentioned, which can be checked in the table of solutions, of not being able to have a closed round trip.

On figure 1*a* we can trace six lines in addition which start from a starting station and go to a destination station. We also note any one of them, for example BC drawn on figure 1*b* closes a polygonal line, in this case with part of the broken line we already have.

Let us see if we can modify the initial solution in such a way as to use the relation BC in some way and the economic results of so doing. As B is a starting point and C a destination, let us travel in the direction BC; let us suppose we are doing this with a wagon. As there will be no modification in the flow from E to F and from G to F, nor consequently from B to F, through receiving a wagon from B at C, D will receive one wagon less, and in its turn will receive one more from A, which in turn will send one less to C, which will be made good by that received by C from B. The use of the route BC will therefore simply mean a readjustment of the flow in the circuit it closes.

Let us see what alteration this will make in the cost. In figure 1*b* we have put the cost beside each of the relations. Running a wagon from B to C adds a further cost of 8, one less between A and C means a difference of 13, one more from A to D an increase in cost of 10 and one less from D to B a reduction in cost of 10. The total change or marginal cost of the run BC is 8 — 13 + 10 — 10 = — 5. I.e. it is profitable, as with each wagon the cost will fall by 5 units. To improve the solution previously arrived at, we must therefore use this saving

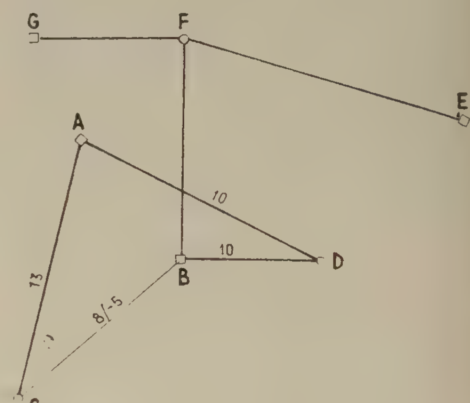


Fig. 1*b*.

to the greatest possible extent by running as many wagons as possible by BC, i.e. 10, the maximum number which can stop going from AC and BD.

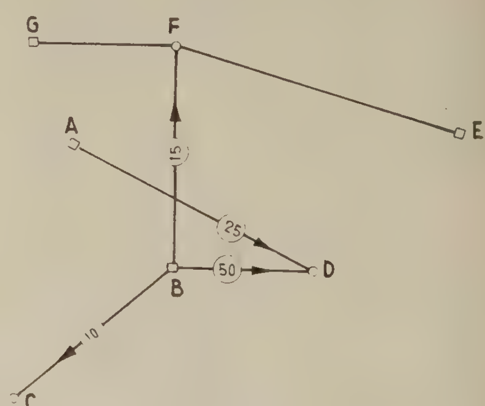


Fig. 1*c*.

In general, it is hereby demonstrated how a solution in which there are closed circuits can be improved by changing

the flow on the different relations until one of them is opened up, except when the marginal cost of any one of the relations is zero, in which case the number of wagons running by this route is immaterial, but in this case equally the solution with an open circuit is no worse than any other one with a closed circuit. In this connection, an endeavour should be made to find the solution if the problem amongst the basic solutions which are those which, shown in the table, have the open configuration explained.

This property simply makes it possible to recognise at first sight that the solutions found in some cases for problems of this type in which the costs are not calculated since the figures are not known, need not be the best.

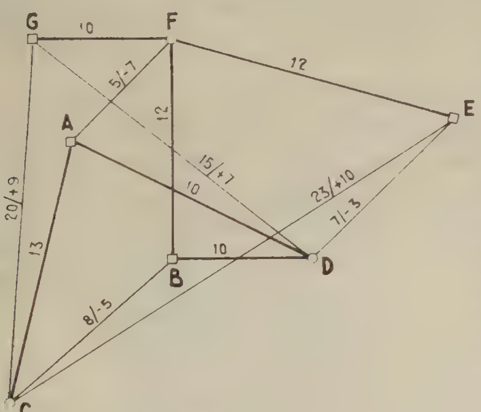


Fig. 1*d*.

It is also justifiable with this property that in ascertaining the optimum solution, starting from an initial basic solution, we should look for another, also basic which is better, which we can do by following the processus indicated. But in order to arrive at the optimum solution, it is logical that we should make a choice amongst the modifications which could be made of those which give an additional increased profit. To do this, with the simplex method, recommendation is made of the rule of determining in the initial solution the marginal costs of all the relations that are not being used, and to choose as the second solution tried, that giving a marginal cost with the negative value of the lowest absolute value. We think it is more logical to modify this rule and select the case not of the lowest marginal unit cost, but the highest total saving, in the way we shall subsequently explain. In this way, we get in some cases a shorter processus, though the number of steps taken in arriving at the optimum solution cannot be less than a certain minimum which is equal to the number of spaces not occupied in the initial solution which are finally shown occupied in the optimum solution.

In figure 1*d*, we have indicated the cost beside each of the relations, and in the case of relations that have not been used, their marginal costs. It will be noticed that three are negative, AF — 7, BC — 5 and ED — 3. But if AF is used, we can send a maximum of 15 wagons and obtain a saving of 105, whereas if we select BC we can only send 10 with a saving of 50, and if we prefer ED, in spite of its less favourable marginal cost, as we can send 50 wagons, the saving will be 150. Because of our rule, we will choose ED.

Returning to the table of solutions on which we established the initial solution (table 10), we can calculate the marginal costs and the savings on another table (11)

or for each of the non-occupied spaces in (10), we calculate and enter in the upper part, separated by a diagonal line, the corresponding marginal cost. For this purpose, having before us the two tables (10) and (9), we take on this latter the path which in (10) will close a run with the case we are considering, by adding and substracting alternatively the costs of (9), i.e. taking them with the — sign under which they are shown in (9) or with the + sign, beginning by the case we are considering. These routes all have a minimum number of four movements in the case of the initial solution, but in the following solutions, we will find that the movements are more numerous. Then, only for those cases having a negative cost, we will calculate and enter in the lower part the corresponding saving, in the way previously explained, i.e. by finding the maximum flow possible which is the minimum number of those in the uneven spaces occupied in the corresponding run.

This gives us table (11) which, because of the spaces it shows as occupied, is

	C	D	F
A			-7 / -105
B	-5 / -50		
E	+10	-3 / -150	
G	+9	+7	

(11)

complementary to table (10), because of which in practice, only one table will be prepared in the form of table (12).

Going over to the second solution from table (12) is very simple. The new space to be used, that of ED which gives the greatest saving closes a run with BD, BF and EF. Only the corresponding flows have to be modified. Relation EF has to be given a flow of 50 wagons, BD 60 less 50, i.e. 10, BF 15 plus 50

	C	D	F	
A	10	15	-7 / -105	25
B	-5 / -50	60	15	75
E	+10	-3 / -150	50	50
G	+9	+7	25	25
	10	75	90	

(12)

i.e. 65 and EF remains unoccupied. This leaves us with the solution shown in table (13) in which spaces AC, AD and GF are unchanged. In this table, we go back to calculating the marginal

	C	D	F	
A	10	15	-7 / -105	25
B	-5 / -50	10	65	75
E	+	50	+	50
G	+	+	25	25
	10	75	90	

(13)

costs and maximum savings which we enter as previously. In this table and the following ones, for the sake of greater simplicity, we only put a + sign in cases of positive marginal costs. We now have to use space AF with a greater saving, and proceeding as before, we go on to the third solution shown in table (14). In this, there only remains one case of a negative marginal cost. We will use

this in another solution, which gives us table (15). In this latter, no unoccupied space has a negative marginal cost, which means that it is the maximum solution.

	C	D	F	
A	10	+	15	25
B	-12 / -120	25	50	75
E	+	50	+	50
G	+	+	25	25
	10	75	90	

(14)

Its cost is 25 × 5 + 10 × 8 + 25 × 10 + 40 × 12 + 50 × 7 + 25 × 10 = 1 535. The processus followed shows the saving at each step. From the initial cost, which as we have seen, was 1910, we have descended by successive steps to :

1910 — 150 — 105 — 100 = 1 535.

As will be noted, each step leads to a fairly substantial saving. It often happens that any deviation from the optimum solution represents a considerable loss, even when it corresponds to wisely obtained solutions.

	C	D	F	
A	+	+	25	25
B	10	25	40	75
E	+	50	+	50
G	+	+	25	25
	10	75	90	

(15)

There are still two points to clear up to terminate the report of this method of solving the problem. The first is as follows. If in table (12) instead of taking ED as the new space to use, we had taken AF which is that indicated by the rule always to select the lowest marginal cost, we could have reached the solution shown in table (16) in which only five spaces are occupied instead of six, as in the initial solution. If we wish to continue the process, we will find that for some of the unoccupied spaces, we cannot calculate the marginal costs. By cancelling six of the unknowns of the

	C	D	F	
A	10		15	25
B		75		75
E			50	50
G			25	25
	10	75	90	

(16)

system (3) of six independent equations with 12 unknowns, with which there remains a given system, we have obtained a system of solutions with 5 positive values and the sixth nil. Such a solution of system (3) or table (15) reveals itself as faulty and to deal with it, following the same method as previously, it is sufficient to bring out this sixth zero value of one of the unknowns. To do this we can lawfully consider that in passing on to (16), we get a zero in AD or BF indiscriminately, and we show this in the space we select between the two of them. In table (17) we have done this, choosing AD, the space with the lowest cost of the two. We then already have a basic solution with which the method can be continued normally.

When changing the solution, degenerations of higher value may occur, cancelling out more than two flows of the previous solution. These cases are dealt with in the same way, writing in the zeros in all these spaces, except one.

	C	D	F	
A	10	0	15	25
B	-5 / -50	75	+	75
E	+	-10 / 0	50	50
G	+	0	25	25
	10	75	90	

(17)

The other supplementary point to be dealt with before this report of the abbreviated method of the table of solutions is complete, is that relating to cases with multiple maximum solutions. In our example, by getting in (15) a table in which all the non-occupied spaces have positive marginal costs, we have a definite proof that this is the optimum solution and that there is no other. But in other cases, it may be different.

For example with the problem whose data are given in tables (18*a*) and (18*b*), we get the optimum solution shown in table (18*c*) in which the space AG has a zero marginal cost. This means that using this route, sending by it no matter what flow to the greatest possible limit, will give an equal total cost, and consequently produce many other optimum solutions. In our case, the maximum possible flow is two wagons, so that there are only two solutions, one with one wagon and one with two wagons, as shown in tables (18*d*) and (18*e*). This latter is a second basic solution, whilst the former is not a basic solution which can be obtained as the linear combination of two basic solutions and precisely as a half-sum.

(18)

a)

	D	E	F	G
A	-5	-3	-1	-9
B	-15	-17	-3	-2
C	-3	-2	-1	-8

b)

	D	E	F	G	
A					8
B					4
C					9
	4	8	3	6	

c)

	D	E	F	G	
A	+	5	3	0 / 0	8
B	+	+	+	4	4
C	4	3	+	2	9
	4	8	3	6	

d)

A		4	3	1	8
B				4	4
C	4	4		1	9
	4	8	3	6	

e)

A		3	3	2	8
B				4	4
C	4	5			9

It is easy to generalize this result in cases with a large number of intermediate solutions, which are very easy to find by the processus given, as in the case where in the first optimum solution there is more than one space with a zero cost.

Returning to our simple example, in

	C	D	F
A	-13	-10	-5
B	-8	-10	-12
E	-23	-7	-12
G	-20	-15	-10

	C	D	F	
A	10	15	-7 / -105	25
B	-5 / -50	60	15	75
E	+	-3 / -150	50	50
G	+	+	25	25
	10	75	90	

19)

	C	D	F	
A	10	15	-7 / -105	25
B	-5 / -50	10	65	75
E	+	50	+	50
G	+	+	25	25

	C	D	F	
A	10	+	15	25
B	-12 / -120	25	50	75
E	+	50	+	50
G	+	+	25	25

	C	D	F	
A	+	+	25	25
B	10	25	40	75
E	+	50	+	50
G	+	+	25	25
	10	75	90	

order to show the whole of the processus followed, we have given below tables (9), (12), (14) and (15) in the arrangement in which it might be useful to establish them in practice.

It is possible to check that the material labour which the application of the method involves is easy and rapid. With some practice, an operator accustomed to mental calculation, can complete this processus in a few minutes. But in this connection precisely, to speed matters up, the method allows of an important improvement which we will now examine. In the previous development, we began by finding an initial solution by the N.O. rule in spite of the fact that in this case this initial solution was a long way from being the optimum one, because we were illustrating in this way the use of this easy rule which is so simple, and to make it easier to understand the method by explaining how certain steps follow one another.

But as soon as we think about it, it is clear that it is possible to start with a better solution, one that is closer to the optimum and as a result in practice it is customary to succeed with very good initial solutions. The basic principle is to select as the occupied spaces those with the lowest costs and not those which follow a certain order. We will give two methods of applying this principle.

One practical method is to use the « double preference » spaces (see ref. no. [24]). This name is given to those spaces corresponding to the relations in which the costs are seen to be the lowest in the line and column of the table. In our case, in the table of costs, which we give in (20*a*), we see that the three

spaces AF, BC and ED which we have marked in (20*b*) meet these conditions. We will attribute the maximum possible flow to each of them, taking into account

	C	D	F
A	-13	-10	-5
B	-8	-10	-12
E	-23	-7	-12
G	-20	-15	-10

a)

	C	D	F	
A	-	-	25	25
B	10			75
E	-	50	-	50
G	-			25
	10	75	90	

b)

20)

	C	D	F	
A	-	-	25	25
B	10	25		75
E	-	50	-	50
G	-	-	25	25
	10	75	90	

c)

	C	D	F	
A			25	25
B	10	25	40	75
E		50		50
G			25	25
	10	75	90	

d)

the total figures of surpluses and requirements. Consequently the spaces AC, AD, EC, EF and GC will remain unoccupied and we need only use the remaining three of the four not marked in (20*b*). Only amongst these, need we look for the « double preference » spaces in (20*a*) which are seen to be BD and GF to which we will attribute in (20*c*) the maximum flow taking into account the total remaining available. In (20*c*) there is no other space that can be used except BF; marking this 40, the conditions of the problem are fulfilled. We have obtained an applicable basic solution, which we can take as our initial solution. But recommencing the previous processus, we see that this very solution is the same single optimum one we have already found. We must mention here that in this method of establishing the initial solution, the spaces to be used cannot always be determined so certainly and quickly, as « double preferences » cannot always be found; in addition, it is necessary to check that the solution found meets the condition of basic, applicable solution, in the way we have indicated, and take care to complete the resulting selected spaces, by applying the criterion given with others which form with the first a basic solution.

Another method which seems to us preferable in some cases and likely to lead to a solution which is certainly a basic one, is the following which is inspired by the principle : « avoid high costs ». The line (or column) with the highest costs is chosen, which in our case is the last one, and we ascertain which is the lowest cost, which is GF. We give this the maximum possible flow,

with which the remaining spaces of a line or column, in our case the last line, will remain occupied : (21*b*). It is then necessary to find in column GF the lowest cost which is that of AF, the remaining spaces of first line being unoccupied (21*c*). The cost of the two spaces remaining in the last column is the same. We select that of the line which has the other highest costs, which is the third, and we continue, as will be seen, on a broken line which assures that the solution arrived at is a basic one, merely having to avoid any cases of degeneration as already known. In our case this gives us solution (21*f*) which is not a maximum, but starting from which, we can arrive at the maximum in a single step.

By one or other of these two processus or by any other derived from the same idea of selection, as initial solution, of the lowest costs, we can get an initial solution which, if it is not the optimum is close to it, thereby shortening the length of the processus and greatly facilitating its use in practice.

All the above refers to what we might call the general case, in relation with the number of starting and destination stations. When the number of such stations is two or three in each case, it is possible to make a simplification, as we shall now explain.

III. Simplification in elementary cases. Graphical method of dividing up into a star.

The abbreviated method we have just described is considerably simplified when the number of starting or destination stations or points is reduced to two,

a)

	C	D	F
A	-13	-10	-5
B	-8	-10	-12
E	-23	-7	-12
G	-20	-15	-10

21) b)

	C	D	F	
A				25
B				75
E				50
G	−	−	25	25
	10	75	90	

c)

	C	D	F	
A	−	−	25	25
B				75
E				50
G	–	–	25	25
	10	75	90	

d)

	C	D	F	
A	–	–	25	25
B			−	75
E			40	50
G	–	–	25	25
	10	75	90	

e)

	C	D	F	
A	–	–	25	25
B			–	75
E	−	10	40	50
G	–	–	25	25
	10	75	90	

f)

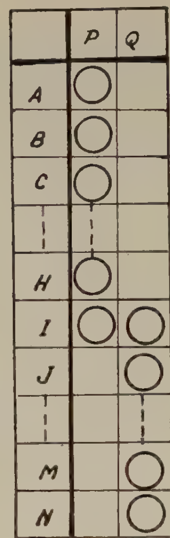
	C	D	F	
A	–	–	25	25
B	10	65	-3 / 120	75
E	–	10	40	50
G	–	–	25	25
	10	75	90	

and it is very interesting to study this simplification. In the first place, we see that as the problem unfolds, there is no point in making a permutation between the groups of starting or destination stations, which merely involves a modification in the position of the table, replacing the lines by columns. We will therefore suppose that we are faced with a problem in which there are only two destination stations and a number n of starting stations.

We note that in such a case, by making a suitable mutual arrangement of the starting and destination stations, the *configuration of the spaces occupied within the framework of any basic solution must be those of table* (22). In fact, there must be at least one row with two occupied spaces, as otherwise there would only be n occupied spaces instead of $n + 1$, which are those corresponding to a table of fixed dimensions, and there cannot be two rows with both spaces occupied, as the principle is complicated by the fact that of the spaces occupied a closed spiral cannot be made. As a particular example of this configuration we can take that in which the space IP or IQ will be unoccupied in case of the degenerated solution.

For the solution shown in table (22) to be the optimum one, it is necessary for all the unoccupied spaces to have positive marginal costs, consequently for a space in column Q and line previous to I, it must be :

$$-C_{CP} + C_{IP} - C_{IQ} + C_{CQ} \geqslant 0$$



22)

and for a space of column P and line after I :

$$-c_{MQ} + c_{IQ} - c_{IP} + c_{MP} \geqslant 0$$

or :

$$c_{CP} - c_{CQ} \leqslant c_{IP} - c_{IQ} \leqslant c_{MP} - c_{MQ} \qquad (23)$$

a result which covers the case of the degenerate solution, without attributing the zero flow to the space IP or IQ in question.

This means that for each of the starting stations we find the difference in their costs to those of the destination, *the series of these differences is such that starting points which must only supply one destination are lower than those which must only supply the other destination, and there is at least one number which separates the two groups of differences. There may be one or several starting points which supply the two destinations*; *in this case, their differences in cost are equal between themselves and for this limited number.*

We will illustrate this important result by an example developed graphically, a method which moreover is interesting in itself. We will suppose that there are five starting points A, B, C, D and E and two destinations P and Q, and that therefore coordinated by differences of cost with the two destinations, and to solve the problem graphically it is not necessary to draw in all the branches of the hyperbola but merely to mark on the straight line PQ the points A_1 B_1 C_1

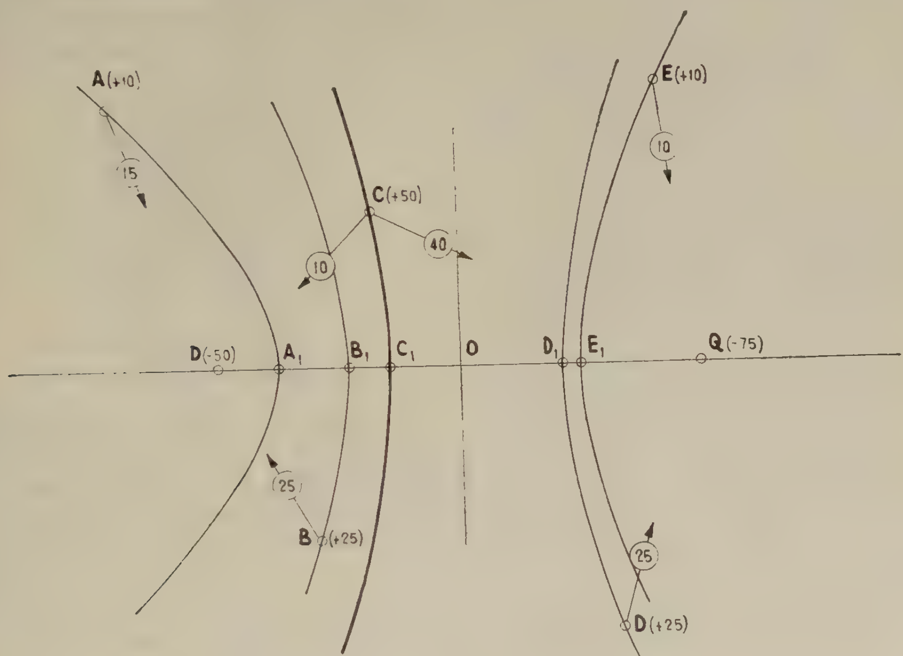


Fig. 2.

the cost of transport is exactly proportional to the geographical distance by a straight line. The geographical map (fig. 2) gives us in this case the scale of costs and the curves of equal difference in cost are the branches of hyperbola with their seats at P and Q. Undoubtedly, for a supply to P, it is more profitable to use wagons from A than from any other source, according to the arrangement of the branches of the hyperbola which pass through each of the five different starting points. These are D_1 and E_1 determined by the differences in cost, seeing that O is the mean point of P and Q :

$$\overline{OA_1} = \frac{1}{2} (\overline{A_1P} - \overline{A_1Q})$$

This graphical construction can be done without the costs being proportional to the distances, by modifying the distances obviously so that they represent, on a suitable scale, the costs involved. It is not necessary for the points represent-

ing P and Q to appear on the drawing, but is is necessary to note the direction in which the differences run. The points are easily divided amongst the two groups by a consideration of the number available and needed.

One particular case of the example we have just solved graphically would be that in which the starting stations were arranged geometrically on the line PQ on such a line or path, that running through this, we could come to each one of them in turn. Even if the costs were not proportional to the distance, the conclusions would be similar. Intuitively, it appears evident that the requirements of P should be met from the stations lying more to the left, taking them in order until P's requirements are fully met. When the costs are proportional to the distances and use is made of a diagram like figure 2, if the limiting point is the same P or Q, there may be points on it representing more than one station and the solution may be multiple.

This particular case can be extended when on a line there are different destinations at the same time as different starting points. In the same way, it is obvious that in this case we would have to begin by sending to the destination furthest over to the left, the wagons from starting points furthest over to the left and then the following ones, until the first destination has had its requirements filled, and then continue by supplying the second, and so on.

Let us now return to the example solved graphically, to consider how it would be solved by the table method.

The costs are those which appear in the first two columns of table (24) in which the differences have been determined in the third column. In this table, the starting stations have already been entered, in the order of the above differences. If there are two or more showing the same difference, one or other of them will be placed in some given order before the other one or other ones.

	P	Q	P-Q
A	-14	-32	+18
B	-10	-21	+11
C	-11	-18	+7
D	-24	-11	-13
E	-26	-14	-15

24)

The numbers available at the starting points being known, the problem is limited to finding the point of separation meeting the requirements of P and Q, sending to P the number available in

	P	Q	
A	15		15
B	25		25
C	10	40	50
D		25	25
E		10	10
	50	75	

25)

successive lines until its requirements are filled, and to Q all the remainder. The solution will be of type (25) or (26) according to the case. If the separation corresponds to a station which has the same difference in cost as others, there

will be more than one maximum solution; all these solutions can be found very easily.

In figure 2, we have shown the solution for the case given in table (25). For a case like that shown in table (26), the separation between the area of the starting points corresponding to P and those

	P	Q	
A	15		15
B	25		25
C	50		50
D		25	25
E		10	10
	90	35	

26)

corresponding to Q is not a given hyperbola amongst those passing through the given points, but any one of the hyperbola of the same origin from those which pass through two given points; in the case of the table (26) an intermediate hyperbola amongst those passing through C and those passing through D, for example on the perpendicular axis at O on the straight line PQ. But as we have already remarked, the geometrical construction needed to find the solution of the problem is reduced to a linear construction on the straight line PQ. This is a very important observation, which makes it possible to extend the geometrical method to cases in which the number of starting or destination stations is three, such as the case we solved in the previous paragraph by the table method. In this latter case, there were three destination stations, and we based our working on this case, which is also applicable when there are three starting points, in view of the existing mutuality as we said.

Les us go back to the example dealt with in (8) and (9) arguing as follows : if in the given problem, which we will take as solved, we do away with the movement from each starting point to one of the destinations, for example D, reducing in consequence the numbers available, the flow remaining at C and F will be arranged in such a way that the previous condition will be fulfilled so that the corresponding differences in cost according to (24) remain separated, seeing that the problem remained reduced to the previous one. In other words, the number will be such that the difference in cost $c_{NE} - c_{NF}$ of the remaining stations will be divided by it into two respective groups, one larger and one smaller than it. We will even say, in considering the flows from all the starting stations which do not go to C, that there will also be a number Y such that the differences in cost will be divided up in a similar manner. Therefore, if for each of the starting stations, we cal-

	C	D	F	C-F	D-F
A	-13	-10	-5	-8	-5
B	-8	-10	-12	4	2
E	-23	-7	-12	-11	5
G	-20	-15	-10	-10	-5

27)

culate the differences in cost at C and F and at D and F, as we have done on table (27), and take their respective values as the cordinates x and y of the points representing the respective stations in an ordinary Cartesian system, the

result will be couples of numbers (X, Y) such that the straight line $x = X$ will leave to the left those starting stations which send a few wagons to F and to the right those which send them to C, and the straight line $y = Y$ will have below it the stations which send some wagons to F and above it those which send them to D. The right angle formed by the half lines starting from the point XY and running in the suitable direction will include the points representing the stations which send wagons to F; on the sides of the angle there may be some stations sending wagons to F and C or F and D, and the top may coincide with the point representing one or several stations which may send wagons to all three destinations.

The stations which do not lie within the above right angle, i.e. those which do not send wagons exclusively to F, will have their differences in cost to C and D also separated in a similar fashion, i.e. there will be a number at Z separating the higher and lower costs which correspond to the stations which send wagons to D and C. But making :

$$C_{NC} - C_{ND} = (C_{NC} - C_{NF}) - (C_{ND} - C_{NF}) = x - y$$

the equation :

$$x - y = Z \text{ .... or } y = x + Z$$

represents a straight line parallel to the bisector of the first quadrant, which separates to one side and the other the points which make $x - y < Z$ from those which make $x - y > Z$, i.e. the point representing the stations which send wagons to C from those which send them to D. This straight line must obviously pass through the top of the right angle which, belonging to both sides, must lie on the division between the region with destination C and the region with destination D.

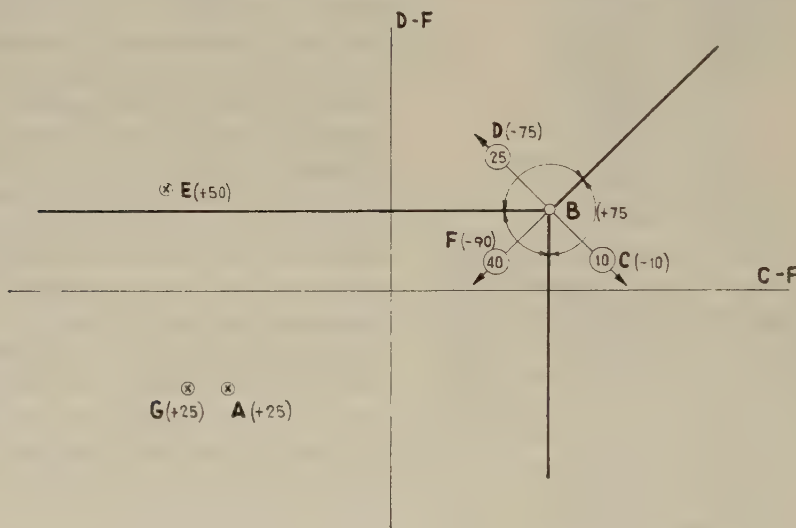


Fig. 3.

There is therefore a « star », like that roughly drawn in figure 3, which separates into three regions which contain the consecutive angles forming it, the points which must send wagons to all three destinations.

To solve the problem graphically by this method, once the points A, B, E and G have been sited on the plan x, y by their coordinates the columns 4° and 5° of table (27), all that we have to do is to imagine a star like the one just described and move it about till the sides are all parallel to the directions which correspond to surplus wagons at points in each area, or on the sides, and are distributed according to the needs of each of the angles. This operation, although it has to be done by trial and error is very simple and can be done very quickly. In the figure, the star is in the position corresponding to the solution of the problem, as explained in the previous paragraph.

This method has the advantage that the position of the points on the drawing does not vary, whilst the points of origin and destination and the costs of transport are not distinct one from the other, which makes it possible to use the same drawing to solve many problems in which the surplus wagons and wagon requirements vary.

In a manner similar to that followed when changing from the case of two stations to that of three, by passing through the linear space on the plan, it is possible to continue it by extending it to n stations, working in space $n - 1$ dimensions, as worked out in the study (25). But it is obvious that the method has already lost the great advantage of being quick to use in practice; for this reason we will not insist upon this point.

IV. Case in which the total number of surplus wagons does not coincide with the total number required.

At the beginning of paragraph II, we supposed that the total number of wagons available was equal to the number of wagons required. It is very easy to abandon this restriction, when the method will be more closely in line with real conditions in practice. Owing to the mutual property we have already mentioned, the problem will still be the same, whether there are more or less surplus wagons than the number required. Let us suppose that there are more and we will study it by altering our example, supposing that the data of (I) are all unchanged except that there are 40 wagons available at A instead of 25, and consequently in the whole a surplus of 15 wagons.

In the final solution, for it to be optimum, there will obviously have to be 15 wagons which have remained in their stations, seeing that only the number of wagons required must be moved from the starting stations. We must therefore use as one of the unknown factors of the problem, the number of wagons from each starting point which will remain there, as if this were a new fictitious destination, its cost of transport obviously being nil.

To apply the method of the table to this case, we have used the artifice of adding an additional column in which the space on each line corresponds to the surplus which remain in their respective starting stations. This is equivalent to turning the problem into a different one,

having the same value, in which there is a new destination to which the wagons might be sent from any given starting point, with a zero cost.

28)

a)

	C	D	F	Sob.
A	-13	-10	-5	0
B	-8	-10	-12	0
E	-23	-7	-12	0
G	-20	-15	-10	0

b)

	C	D	F	Sob.	
A	+	+	25	15	40
B	10	25	40	-7 / -105	75
E	+	50	+	-4 / -60	50
G	+	+	25	-5 / -75	25
	10	75	90	15	

c)

	C	B	F	Sob	
A	+	+	40	+	40
B	10	25	25	15	75
E	+	50	+	+	50
G	+	+	25	+	25
	10	75	90	15	

In the table above (28), we have developed the solution of the problem. The part (28*a*) is the new table of costs, which is the previous one with a new final column of zeros. In *b* we have tried the first solution, but in this connection we have to make an important observation. The simplex method has the advantage of being usable in many cases, so that it is possible to pass from the solution of one problem to that of another altered one by using the solution or solutions already obtained. For example, in our problem, we have taken as the initial solution, that constituted by the final solution of the previous problem, table (20*a*) with the addition of a 15 to space AS. This solution is basic as only one occupied space has to be added when a column has been added. If, to pass on to the new conditions, we have to add more than one occupied space, the processus would involve identical operations, when we would have had to check the closed and open circuits at the most suitable position and in addition, check if one of the new circuits which might be closed had negative marginal cost.

In any case, taking as the initial solution that of the previous problem, we know that the empty spaces in the previous table have a positive cost, and that it is sufficient to check those in the column added by the process already known. In our case, with one step, we arrived at the optimum final solution, which gives a saving of 105 on the previous problem.

V. Case in which account is taken of the surpluses and requirements for several days. Dynamic problem.

In the case we have just presented, there were still some surplus wagons available in the day for which the problem was solved. Naturally, in practice, there are fluctuations in surpluses and requirements, although in the long run these must cancel each other out. But there will be a chance every day to allocate the surplus of one day to cover the excess requirements of the next.

In other applications of the transport problem, separate situations may exist when they will have the aspect we have considered so far. But in the allocation of empty stock, the situations vary and change day by day with great rapidity. It is easy therefore to understand the value of studying the problem theoretically in this new light, by combining the surpluses and requirements of different successive days.

	C	D	F	G	
A			40		40
B	25	30	20	10	85
E		50			50
	25	80	60	10	

29)

In order to show the importance of this much more complicated perspective, we will study a very simple example. Let us suppose that the day after that in which the situation presented in (28) occurred, the position was as follows :

A	+	40
B	+	70
C	—	25
D	—	80
E	+	50
F	—	60
G	—	10

As we kept the 15 wagons that were over from the day before at B, on the second day, we have included these 15 additional wagons, i.e. 85 in all. The problem includes the solution given in the table (29) the cost of which is 1 400. As the cost of the solution (28*c*) is 1 430, the total cost for the two days would be 2 830.

But if on the first day, the needs and requirements of both days had been known, it would have been much better to solve the combined problems, the data for which would be :

	1st day	*2nd day*	*Total*
	—	—	—
A	+ 40	+ 40	+ 80
B	+ 75	+ 70	+ 145
C	— 10	— 25	— 35
D	— 75	— 80	— 155
E	+ 50	+ 50	+ 100
F	— 90	— 60	— 150
G	+ 25	— 10	+ 15
	+ 15	— 15	— 0

the solution being that of table (30), with a cost of 2 740, which saves 90 on the total cost obtained by the method in which the situation each day is solved consecutively. We can divide up the position (30) as follows : the first day,

	C	D	F	
A			80	80
B	35	55	55	145
E		100		100
G			15	15
	35	155	150	340

30)

the wagons already available can be distributed according to table (31) at a cost of 1 460. Of the 15 wagons remaining at G on the first day, 10 will meet the requirements at G on the second day,

so 5 are surplus and the solution in table (32) is the result at a cost of 1 280.

For the first day according to the table (28*c*) we got costs of 1 430, and

	C	D	F	Sob.	
A			40		40
B	10	25	40		75
E		50			50
G			10	15	25
	10	75	90	15	

31)

now, with (31) they are 1 460 which is higher but against this the solution (32) for the second day is much better than that of (29), and the total result is more favourable.

	C	D	F	
A			40	40
B	25	30	15	70
E		50		50
G			5	5
	25	80	60	

32)

But this way of solving the problem for several days simply by adding up the data is too simple. In the case reported, the needs of the first day were met in time, but in other cases it might not be so. It will be understood that to leave the requirements of one day unsatisfied in order to meet those of the next day or even to keep wagons in a station against possible future requirements, cannot be without economic ill-effects, in view of the fact that it is against customer's interests as well as involving a poorer user of the wagons.

This can be evaluated, as it has as a result an increase in the cost of transport from one station to another, when this is done to meet requirements from the surplus of several days. This increase would be the greater, the greater the number of days the wagons were kept idle or loads kept waiting, i.e. if C gets a wagon from A the day it is wanted, it will cost for example 13, but if it is only received the day after, the cost will be taken as $13 + p$; if it is two days afterwards, it will be $13 + 2p$ and so on.

Therefore setting out the problem for each day depends on the solution used the day before and all the problems for successive days are closely bound up with each other. The resulting problem, a much greater one, comes within the framework of the « dynamic programming » studied in different works, for the general case of the linear programming.

We can apply the method of the table of solutions to this dynamic case in the following way. In a table of dimensions as large as is necessary, we will insert in the first column the starting stations according to the data for the first day, then those for the second day and so on throughout the period we are studying. In the first row, we will do the same for the destination stations. Those corresponding to the different days will be distinguished by using sub-indices. In the last row and last column, we will write in the figures for surpluses and requirements. We then consider the case as a single problem in which a station A_i can send wagons to any station C_j. The table of

costs will show which one agrees with the costs given taking any increases into account, seeing that the starting points and destinations correspond to a different day. Theoretically, the problem has a solution, as it is no different from the one we have solved and in practice, and though owing to its complication it is beyond the capacity of manual calculation, it can be dealt with by electronic calculators with no other limits to the size of the problem than those of its limited possibilities, large as these are. In certain cases, a problem covering several days set out in this way can be calculated by hand, but in general unless the number of days is only very small and likewise the number of stations, the manual method is impracticable.

In any case, it is useful to point out that it is possible to take as a starting point for the calculation a basic solution consisting of the solutions obtained separately for each day, completed by zeros in the suitable spaces so that the whole becomes a basic solution as in (33). We might add that the use of tables for several days, of the type of (33) car be used in cases where the details of the transport of wagons from the starting points to the different destinations are different, so that it is necessary to provide that on arrival they will cover the requirements of different days, though, for brevity's sake, we will not go into details of this undoubtedly very complicated case.

	C_1	D_1	F_1	C_2	D_2	F_2	G_2	---	---	---	
A_1											40
B_1											75
E_1											50
G_1											25
A_2											40
B_2											70
E_2											50
¦											¦
¦											¦
¦											¦
	10	75	90	25	80	60	10	---	---	---	

33)

We may therefore consider that we have given a brief idea of the theory involved in our problem. We must add a few considerations about important aspects of its practical application in the allocation of wagons.

VI. **Practical application of the model.**

Many problems solved by operational research make use of a certain mathematical theoretical model on which it is possible to check whether data taken from actual facts can be perfectly fitted in. In the preceeding paragraphs, we have described the type of mathematical model which can be applied to the distribution of wagons. Already, by this means alone, interesting results can be obtained in simple cases where the practical data can be known with sufficient accuracy and in those where the number of stations is but few. For example, it would be elementary to apply what has been described above to make out periodical programmes for the allocation of wagons between the main regions or zones of a railway system, with a much greater probability of economy in the non-paying mileage than were such an allocation left to the care of an official, no matter how experienced.

But, in general, to apply the type of model described to the daily programming for the distribution of wagons throughout the system, steps must be taken to make it agree with each particular case and with the needs which have to be solved, and this in itself is another problem; in other words, it is in this case the very problem of operational research.

At the beginning of Chapter II, we reported how we allow certain hypotheses in order to obtain a simple and well determined proposition of the problem. We will now revise each of them, and consider which of them are real conditions and what course must be followed in order to adapt it to the model.

In the first place, there is the question of the number selected for a limited number of stations or centres in which there are too many or too few wagons. Obviously, on no matter what railway system, there is a very large number of stations, and in considering solely the problem of movements between zones or large regions means we are only dealing with a part of the problem, which is the preamble to another that has to be solved and also involves the fact that it can be considered that in each region or zone, there is only a single destination or a single starting point for movements between zones, just as there are no junctions with other railways which can also be other starting points for the wagons.

The problem for a railway system in its entirety and in all its complexity requires the separate consideration of each station or point where wagons are loaded or unloaded and where empty stock is sent out or brought in. With such a complete system, we can introduce certain reductions which will simplify the problem. In the first place, we can reduce any branch or line which is only connected to the rest of the system at one point, to this one point, which will be a starting point or a destination according to whether the surplus wagons on the branch are more or less than the requirements : on the branch line, some of the stations will have to be adjusted from others, as is done on a linear configuration, as we have seen.

A second reduction will be of the secondary stations or those with little traffic, which in practice with certain systems of operating depend upon another station-centre or more important station, which also have to adjust their requirements as between themselves, organising the transport of empty wagons locally, in

such a way that we can concentrate the total result in the centre station or important station.

There still remains, however, a considerable number of such stations and branches between which the distribution of the empty wagons must be studied. It would appear logical to solve the difficulty by dividing it up into two or three stages so as to obtain a concentration on the local level, on the regional level, and finally the total picture. In support of this is the fact that the application of the method depends upon rapid information concerning requirements and surpluses, and this is obtained from a system of information which in general follows the hierarchical ways.

In general, in the operating of railways, it is usual in practice to have the total stock of wagons of each category distributed amongst the different organic units, regions, zones or American divisions, a distribution which for certain classes of stock with definite characteristics, and for wagons in general, is based on the level of inventories or contingents which are periodically revised. Not only is this practice compatible with the application of this method, but it may also prove fairly advantageous as a practical method of solving some of the difficult practical problems, as we shall see further on. This custom of making an inventory per zone or division being admitted, the problem is to send the number of wagons in excess, at any given moment, on their inventory in certain zones to other zones in which there is a shortage. This manner of solving the problem makes it necessary that in the final scale of the railway as a whole, the zones or divisions are taken as starting or destination points. Nevertheless, it is not certain that in every case the solution of the allocation of empty wagons can be built up in a parallel way in the operating service and that of organising it by stages may be one of the points to solve by means of operational research, as well as the number of separate centres in each local or regional scale that must be selected.

The determination of the number of centres is essential from the point of view of the simplification or complication of the problem. It can be understood why American railways faced with a system of some complexity but having above all a great many junctions with other systems, for each of which the exchange of rolling stock must be considered separately, which are so many starting or destination points, in relation moreover with different divisions, are nearly always in the same case as the tables of solutions of large dimensions for which it is necessary to make use of computators even when studying the problems of a single day.

In setting out the problem, we began on the one hand with the supposition that at the end of each day's work, the allocation centre for empty wagons had a knowledge of all surpluses at each starting point and all requirements at each destination, i.e. they were informed daily of the number of empty wagons at each station and the number required for the following day. The procedure by which this can be known from day to day and for all stations is not an easy one, far from it. It is a problem of communications, of the transmission of information for which modern systems of communication by means of teleprinters and other methods must be used, coordinating these

with other problems bound up with them, which the railways are now solving or trying to solve, in relation with the circulation of the wagons, such as the statistics giving information about the wagon position, that of the wagon routes and trains, that of the returns for exchanges of wagons belonging to foreign companies, and including the traffic statistics.

In actual fact, we have come across cases of companies who have set up large mechanised offices to obtain certain of these statistics, but because such statistics are used by different departments or applied to different aspects of transport, they are sited at different places on the undertaking; such an arrangement deprives them of co-ordination, gives rise to doubling, and to a poor user of the machines. As far as we are concerned, it is extremely important, above all from the economic point of view, that all statistics in relation should be co-ordinated together from the beginning and studied together with the basic documents and methods of transmitting information; we would even dare to suggest as a matter of prime necessity that all plans for statistical mechanisation in the future should take into account the co-ordination of these different separate statistics and their applications, as with those with which we are concerned. Indubitably, the information already obtained regarding the position of loaded and empty wagons, in transit, and exchanges of stock, could be used for a statistical inventory of the empties, or completed as required with the necessary information. Whatever be such information and whatever the processus of its transmission this is another problem to be solved in each case of an individual investigation into the application of the method.

At first sight, it appears that in addition to the statements of the composition of trains or rolling stock sheets, or the transmission statements, other basic documents are needed giving the daily relations of the wagons unloaded in each station. It is possible, however, that a telegraphed announcement of the forecasts of wagons unloaded, collected and summarised in the control posts or centres which would retransmit them by teleprinter, with a subsequent check from the documents corresponding to the movements to be made, might be a practical and effective solution. The statistics already kept give the monthly accounts of all movements made by each wagon. The additional information which we think would be clearly specified would fill in any gaps in this matter.

In our opinion, the nature of the problem and its size do not differ very much from those covered by other statistics for which admirable solutions have been found on some American railways, both as regards speed and efficiency, in spite of their special difficulties.

According to our information, until quite recently, no company had solved in its entirety the problem with which we are dealing. But according to certain information, the « Southern Pacific » has solved it (17) and (18), and since last summer has been allocating its wagons by applying this model of linear programming, carrying out the calculations with the help of computators.

Mention must be made of certain interesting characteristics of the solution

given by the « Southern Pacific » as described in (27). The general configuration of the system is a simple one, almost linear, with a current of empty wagons in one direction, but with a possibility of changing the classification of the wagons, by transferring them from one to the other of the four categories into which they are divided according to their condition and suitability for transporting various goods, which greatly adds to the complication of the problem; as does the difficulty common to all railways of the great number of branch lines with exchange of rolling stock with other systems. They have introduced an inventory or constant park per division, which is checked and revised by the results of a system of information set up to control the allocation. As documents for the basic information use is also made of the daily wagon statements from each station.

There is little to be added as regards the question of obtaining from the other group information corresponding to wagon requirements, which in many companies is solved to a sufficient extent by the transmission of communications by the usual means and by a system of allocation officers. All that has to be done would be to adapt the system to the model as well as the particular case of its application.

As we have said, a practical solution of this point can be facilitated by adopting average inventory levels for existing wagons in each zone or division, which can be checked or revised by the same system of communicating information, and which can be corrected each day by the information received regarding requirements and surpluses, not only for one day but for several days in succession, knowledge of which leads to increased benefits from the application of the model.

It would appear difficult in reality to obtain such information in advance, and this is generally the case; but in some cases, for example regular freight services, purely and specialised traffic, etc., the circulation of certain stock can be based on a definite programme, making it possible to foresee with a certain amount of accuracy what groups of wagons will be available in certain places as well as what stock will be required. These particular estimates can be used to correct and complete the statistical forecasts which can always be made, by means of which it is possible to fix the existing inventories or special parks we mentioned. By means of a study which should form part of operational research in its application to the model studied, it is possible to determine the most likely figures of surplus and required wagons, by comparison with those recorded during comparable periods of the same week of the previous year, of the previous week, during a similar harvesting period, etc., and the figures ascertained in this way for periods of several days can be corrected from those then actually obtained.

It would however appear of somewhat doubtful value to complicate the study by trying to solve it for a period of many days, starting from merely approximate figures.

It might be useful in certain cases to follow a processus on the following lines. Solve the problem of the first day, with accurate data from the numerical dimensions of the table, which we will suppose

set up for electronic computation; determine the position for a second day, and solve the problem with a table of type (33) as explained in the previous paragraph, and then proceed to do likewise for another day and so on; until the capacity of the computator is reached, by considering each time the part of the solution covering the programme for the first day, which is the only one that has to be carried out immediately and the saving obtained in each case, by interrupting the processus when the final gain seems to be negligible or below a certain predetermined value.

There remains to deal with the cost of transport of wagons between the stations, which we will take as known. In many cases, such costs can be effectively determinded by the usual calculations of costs or by special calculations made for this purpose. It is important to point out in addition that what is of even greater value than knowing the total cost of the optimum solution, is to determine what is this optimum solution and the saving it will give, and that it is not essential to know the total cost of transporting wagons from one station to another, but rather the marginal costs, which it may be easier to determine. In cases when information concerning the costs is not regularly obtained by an administration, another function of operational research will be in this case to determine these costs by solving the problem, by obtaining in practice suitable information by soundings and special calculations.

We wish to point out that throughout this article we have spoken of costs, but the model can be also used to minimise any other factor which it is desired to reduce instead of the cost. It may be the mileage, the train times, etc. The results will be very similar, and the basic information may be a great deal easier to calculate. Finally, it is essential for the problem to be a linear one, and the cost of transporting the wagons must be constant, i.e. it must not vary according to the number of wagons transported. This supposition may be the subject of some objections, but even if these are admitted, the model is a valid one. Suppose, for example, that the cost of transport between A and B is ascertained by more thorough calculations to vary according to a definite scale. We can find the solution by taking as our first sounding the cost corresponding to the number of wagons which we hope to find in the solution from our knowledge or other facts or at first sight. If the solution found lies within the corresponding interval we shall have been successful. If not, we must check it against the actual costs corresponding to it. This second step is facilitated by the observation already made at the end of the previous step in our initial solution, which is no doubt very close to the one we are looking for.

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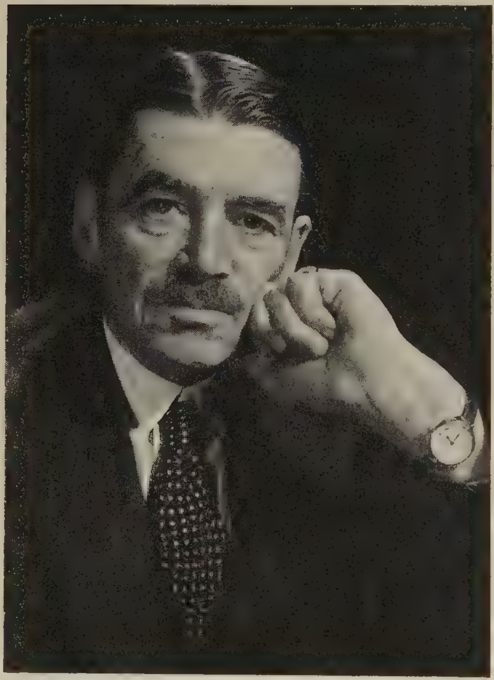
OBITUARY.

Lt.-Colonel G.R.S. WILSON,

Chief Inspecting Officer of Railways, Ministry of Transport and Civil Aviation, Great Britain.
Former Member of the Permanent Commission of the International Railway Congress Association.



(From the «Sunday Times» Portrait Gallery, by Douglas Glass.)

We have learned with deep regret the death on March 20 last, of our much devoted Colleague Lieutenant - Colonel G. R. S. Wilson, eminent member of the Permanent Commission of the International Railway Congress Association.

Lieutenant-Colonel G. R. S. Wilson, R. E. (retired) was Chief Inspecting Officer of Railways at the Ministry of Transport and Civil Aviation, Great Britain, since the 1st August 1949.

He was educated at Marlborough and at the Royal Military Academy Woolwich. He was commissioned in the Royal Engineers in November, 1914, and proceeded to France in May, 1915, serving in field companies there and in Macedonia throughout the First World War. He subsequently commanded a field company in Ireland and in 1921 was employed by the Colonial Office for the survey work of the Syria-Palestine Boundary Commission.

Thereafter, he served with the railway troops at Longmoor, until 1924, during which time he was also in charge of the Catterick Military Railway and was attached to the South Eastern and Chatham Railway for a year's training course. From 1924 to 1930, he was employed in the Directorate of Movements at the War Office, after which he saw two years service in Malta.

He then returned to the Railway Training Centre at Longmoor, where he became an Instructor, after undergoing a training course with the Southern Railway.

In 1935, having retired from the Royal Engineers, he was appointed an Assistant Inspecting Officer of Railways.

Colonel Wilson was recalled to the Army on the outbreak of the Second World War, and served as Assistant Director of Railways with the B. E. F. in France until June 1940, when he resumed his duties with the Railway Inspectorate. He was

appointed an Inspecting Officer of Railways in 1941 and Chief Inspecting Officer of Railways in 1949, as mentioned above.

He became one of the delegates of the British Government on our Permanent Commission on the 5th March 1951.

In spite of his many activities, he was very devoted to the works of our Association and was always pleased to help with all his experience and knowledge in any circumstances. He distinguished himself by his clear sightedness, logic and competence, which make the loss occasioned by his death all the greater.

We feel his loss very greatly and ask his family to accept our sincere sympathy.

The Executive Committee.

CORRIGENDUM.

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There is :

RAILWAY : *London Transport Executive.*

Column (*b*) : 14.5 m out of 480 m.

Column (*j*) : yes

Column (*m*) : expansion joint.

Please read instead of the above :

Column (*b*) : 145 miles out of 480 miles (234 km out of 772 km).

Column (*j*) : No. Adjustment switches are normally locked against temperature movement.

Column (*m*) : machined frozen joints of normal type.

* * *

In addition, in the list of countries given on page 379/1 of the same report, the *Union of Soviet Socialist Republics,* which is included in Mr. A. Crespo Mocorrea's report on the same question must be cancelled.

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General Secretary of the Permanent Commission of the International Railway Congress Association.

(JUNE 1958)

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